Bulletin No. 149
Farm Grain Drying and Storage

CORRECTION

Page 5, Fig. 1C. Caption should read Average relative humidity, August (per cent)

Page 17, para 2, last line. Page reference should read “91”

Ministry of Agriculture, Fisheries and Food.
September 1966

London: Her Majesty's Stationery Office
High efficiency — low power consumption

non-overloading impeller — no risk of motor burnout if resistance should fall

Drip-proof squirrel cage motors bolted directly to casing — no separate belts, shafts or bearings

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CARter THERMAL ENGINEERING LIMITED

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This way grain-drying pays...

—a store which requires little or no maintenance and cuts the cost per ton of grain stored — the most practical (and economical) ducting and laterals on the market — a fan/heater which is exactly right for the job (no waste of power or money), plus experienced advice and assistance to ensure that you get just what you need — at the right price. And you deal with one supplier only.

The Blackburn-Higson building is designed to achieve maximum strength at minimum cost — and it is aluminium clad to slash upkeep costs and eliminate painting. Further, you can erect it yourself — all the steel frame sections are j-g-bult and easy to handle. The building, which is approved for Ministry grant, is 36ft. wide and available in multiples of 12ft. in length (min. 36ft.). It has 14ft. high by 12ft. wide doors, heavy gauge alloy grain retaining walls, is immensely robust, durable and practical. You can be sure of getting the right fan/heater from our range of 53 models — our “Packaway” main air ducting is inexpensive and second to none and we have a choice of laterals, augers and all associated equipment.

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aluminium clad grain store

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The new Bentall Intercontinental Grain Dryer is sectionalised for easy erection, low in height, completely dustless and competitively priced. Ask your dealer for full details.

Bentall Elevators are ruggedly constructed and have many outstanding features—inspection doors in head and boot, slide controls to adjust the rate of feed and self-aligning ball bearings. Outputs range from 10 to 40 tons per hour—dry wheat.

Bentall Conveyors are capable of handling up to 8 tons of wheat per hour. They can be supplied in multiple lengths of up to 130 feet. Also a full range of fittings and accessories. Other models with capacities of 12 and 20 tons per hour.
Farm Grain Drying and Storage

Bulletin No. 149

LONDON
HER MAJESTY'S STATIONERY OFFICE
1966
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Third edition 1966

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Foreword

Corn growing is, and is likely to remain, one of British agriculture’s major enterprises. A very high proportion of the resulting harvest is now handled by combine harvesters, which bring with them problems of grain handling, preservation and storage.

There are many well-tried methods of preserving grain quality which remain unchanged in principle, but developments in the application of such principles follow one another with almost embarrassing rapidity, and choice of method is not easy, even for those with an extensive knowledge of the many types of drying equipment available.

In addition, there are some new techniques for preservation of grain at a high moisture content which makes a choice even more difficult.


W. E. Jones, B.Sc.

Director

National Agricultural Advisory Service

Ministry of Agriculture,
Fisheries
December 1965
Influence of Weather on Harvesting and Storage

The weather affects the moisture content of grain at all stages; before it is cut, between cutting and storage and during storage. It is only during the last stage, that of storage, that the farmer has any direct control over the atmospheric conditions affecting his grain. In the intermediate stage he has a choice of method, stooking, tripoding, windrowing or direct combining; but before the crop is cut he can do little except in the selection of the best time to start.

Average Rainfall

Before cutting, the chief factor which will increase the moisture content is obviously rainfall, but the effects of damp air, dew, fogs and mist cannot be ignored. Near the sea coast with onshore winds the air is generally fairly humid, but saturated air is more likely to be found in inland areas at the end of a calm clear night. It is in the sheltered valley bottoms, the same places which are frost pockets in spring, that crops are most liable to be subject to damp conditions during the night, and the grain there most likely to have a high moisture content in the mornings. Such local influences cannot be shown on a small-scale map.

The more general effect of rainfall can be indicated by reference to the average conditions, and Fig. 1A shows the mean August and September rainfall.

Fig. 1A. Average August-September rainfall (in.)
rainfall over England and Wales. In considering this map it must be remembered that an average merely means that, in the course of time, half the years have less rain than the average figure and half the years have more. The driest areas, which lie around the Thames estuary, in Huntingdonshire and in south Yorkshire, have average August and September totals below 4 in. Most of the country to the east of a line from Tynemouth to Bournemouth, together with that part of the west Midlands lying between Hereford and Shrewsbury, has an August and September average below 5 in. The only exceptions to this are the Cleveland, the Yorkshire Wolds, the Lincolnshire Wolds, and the Norfolk Heights, where the mean figures are slightly higher. As might be expected, the wettest areas are Exmoor, the Welsh mountains, the Pennines and the Lake District.

So far as Scotland is concerned the lowest values are found over the eastern lowlands where the average total for the two months is of the order of five to eight inches.

**Rain-days**

Two other details regarding rainfall of England and Wales should be noted. One is that the average number of rain-days in August varies from about thirteen around the Thames estuary to seventeen in the north and west, and twenty or more in the hills and mountains. In September the figures are slightly less, eleven in the south-east and fourteen to seventeen in the west. On the eastern side of Scotland the average number of rain-days is seventeen to twenty in August, and about fourteen to seventeen in September. The second fact is that, in the west, more than half of the rain falls during the night between 9 p.m. and 9 a.m.; in the east the reverse is true, for more of the rain falls during the day. Rain which falls in the night has more effect on grain moisture content than rain that falls in the day, and a given amount of rain which falls slowly has more effect than the same amount lived storm.

**Dry Spells**

The areas of England and Wales most likely to have spells of three or more consecutive rainless days during August, lie in a belt between the east Midlands and the Suffolk and by September the chances of such spells have decreased considerably, especially over most of East Anglia, although the probabilities are still high in the Fen District. August, therefore, despite somewhat higher average rainfall totals, offers On the other hand, during unsettled weather, the showers during August can be very heavy indeed, and many of our most intense falls have occurred in this month.

**Drying Conditions**

When a crop is wet, the moisture can be removed by some combination of the effects of sunshine, wind and warm dry air. If the air is moist, and contains almost all the water vapour it is capable of holding, it can only hold more
if its temperature is raised. Wind is needed to move the water vapour away from the surface of the plant and to mix it with the surrounding air, and the heat required to change water into water vapour must come from the sun. The best drying conditions are, therefore, strong sun, a fresh wind, and warm dry air.

**Average Temperature**

In Table 1 (see p. 8), are a number of average temperatures for certain typical stations distributed over the whole of the country and covering the months of August, September and October.

As in the case of average rainfall figures, average temperatures must be treated with caution, and it must be remembered that approximately half the months will have temperatures below average and half above average.

Over a period of ten years a reasonable estimate of the average monthly temperatures likely to be experienced may be obtained from Table 2, which gives corrections to be applied to the monthly averages for the three months August, September and October.

For example, at Durham in August, the average temperatures over a ten-year period are likely to be as follows:

54.9, 56.5, 57.2, 57.8, 58.3, 58.8, 59.3, 59.7, 60.1, 60.5

The order in which these figures are likely to appear during a coming decade, is, of course, unknown.

**Effect of Hills**

The lee effect is of considerable importance in assessing drying conditions. Air that has descended behind a range of hills lying across its path is warmer and dryer than it was on the windward side. Much cloud may cover the tops of the range but there are often breaks or even complete clearance in the lee. As a result, areas lying in the shelter of such ranges not only escape some of the rain but also enjoy better weather for drying-out. The effect local and not extend over a wide range of country, but it is quite appreciable in areas such as the Welsh Marches, parts of the Yorkshire dales and behind the North and South Downs. Hill ranges, such as the Cotswolds and Chilterns, lie along the prevailing winds and so do not have such a pronounced effect.

**Relative Humidity**

As is explained in Principles of Grain Drying and Storage on p. 20, there is a relationship between the relative humidity of the atmosphere and the equilibrium moisture content of the grain. In other words, at a given air temperature and humidity there is a lower limit to the moisture content, below which we cannot reduce the grain by natural means. This lower limit decreases somewhat with rise in air temperature, but the main controlling factor is the air humidity.

Now the relative humidity of the air is not a constant factor. It changes

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* All temperatures in the text are given in °F. A conversion table is given in the appendix (p. 164).
FARM GRAIN DRYING AND STORAGE

from hour to hour, that is to say, it has a diurnal range; it also changes from
day to day. It is generally at its maximum when the air temperature is at its
lowest, around dawn, and is at its minimum about mid-afternoon when the
air temperature is highest. On cloudy days the humidity tends to stay high;
its variation is greatest when the day is calm and sunny. In Fig. 1B the upper
curve shows a typical variation of relative humidity at an inland station on a
dull, cloudy, summer day, whereas the lower curve is typical of variations
which occur on a warm, sunny, summer day.

Fig. 1B. Diurnal variation of relative humidity. Upper curve on a dull summer day; lower
curve on a fine summer day.

Figures 1C and 1D give the average daily relative humidity for August
and September. In general, the inland areas have slightly lower average
humidities than coastal regions.

With the large hour-to-hour and day-to-day changes in relative humidity,
it might be thought that these average maps would have only limited use.
However, the moisture content changes in the grain are much less rapid than
the relative humidity changes in the air, and the grain tends to come into
equilibrium with the long-term mean relative humidity.

The average monthly maps therefore, do give some indication of the
relative magnitude of the grain-drying problem. The difference between the
most and least humid areas appears to be numerically small, being only about
8 per cent in August, 7 per cent in September and still less in the winter
months. Nevertheless, the chances of less humid days inland are considerably
greater than on the coast, because the day-to-day variation about the monthly
average is greater. For example, in September the average daily humidity at
Pembroke is 87 per cent, and probably on only two or three days per month
is the daily average less than 80 per cent. In Oxfordshire, the monthly average is 80 per cent, so that on fifteen days per month the daily average is probably less than this figure, and on one day in four it may be less than 75 per cent. If advantage is taken of the favourable conditions which occur in the inland areas, the averages do not adequately represent the real differences between drying problems in the more favoured inland areas and the western and coastal areas.

**Hours of High Humidity**

Although bigger variations about the average thus imply a larger proportion of low-humidity hours, they must also imply a similar larger proportion of high-humidity hours. Statistics are now available for the number of hours when the relative humidity is 90 per cent or more for a number of stations. Fig. 1E shows the average conditions in August. Other months show similar patterns.

The area with the least average number of very humid hours is that comprising the Fylde of Lancashire and the Wirral of Cheshire, closely followed by the Suffolk–Essex coast. Other areas which avoid excess dampness in the air lie in three belts:

(a) the lowlands of the Trent, Ouse and Humber;
(b) the north-south strip from Furness to Hereford along the Lancashire and Cheshire plains and the Welsh Marches;
(c) the Oxford plain, the Thames Valley and parts of Essex and Suffolk.

**Favourable Areas**

It has long been realized that arable systems of farming prevail in the drier eastern counties because the greater root range of the grain crops enables them
to withstand minor droughts and deficiencies of soil moisture. Figs. 1A, 1C, 1D and 1E show how the probability of suitable harvest conditions reinforces these reasons for such land utilization. The crop must be gathered in as well as grown.

Fig. 1D. Average relative humidity, September (per cent)

Fig. 1A shows that most of the land east of Tynemouth, Birmingham and Bournemouth has a relatively low average August to September rainfall. Take away from this area the hill regions and a few places where special conditions apply, and add the relatively low rainfall and good drying conditions of the west Midlands in the lee of the Welsh hills, and we obtain a fairly accurate description of the parts of England where grain crops are mostly grown.

The relative difficulties of drying or storage are best considered by reference to Figs. 1C, 1D and 1E. Figs. 1C and 1D indicate the areas in the centre of England where very good drying conditions are most likely to be found and are probably more significant in dry years; Fig. 1E indicates the areas, summarized in the previous paragraph, where very bad drying conditions are least likely and is probably more significant in wet years. The maps show the *average* conditions. During some Septembers, high humidities can prevail for long periods over most of the country—typical of late blight attacks on the potato crops.

Whenever possible, plans must be made to cope with the worst conditions that may be expected over a reasonable period of years, otherwise times will
occur when it is almost impossible to harvest and store successfully more than a limited portion of a crop.

**Weather Forecasts**

Weather forecasts are obviously of limited value to a farmer faced with the problem of cutting, drying and storing, since the time of harvesting is largely governed by the condition of the crop, and by the men and machines available.

A farmer, when arranging the timing of harvesting operations, would be helped by the regularly broadcast short-range forecasts covering periods of 24 hours with the outlook for the following 24 hours, to supplement his own and local weather lore.

In addition, more precise and detailed forecasts for 24 hours and medium range forecasts for two or three days ahead, are available by telephone from a number of meteorological offices in various parts of the country. A list of these offices is given below. It must be realized that medium range forecasts are necessarily much less accurate than forecasts covering a 24-hour period; indeed, they aim to give the weather type rather than any detailed weather sequence.

The Meteorological Office also issues statements giving the weather prospects for about thirty days ahead. Such statements are issued at the beginning and in the middle of each month. The statement of prospects of weather for the coming thirty days is regarded as a reasonable inference in
the light of present knowledge. However, the methods employed are experimental and liable to be changed. The confidence that can be placed in the conclusions is consequently less than that for forecasts of weather for a particular locality for short periods ahead.

Leaflets giving the weather prospects are issued regularly twice a month, and may be obtained, at a cost of 1s. 6d. a year, post free. Applications should be made to The Secretary, Meteorological Office (M.W.S.), London Road, Bracknell, Berkshire.

Statements of weather prospects are also issued regularly to the press and the Broadcasting Services and are normally given publicity in this way. In addition, telephonic enquiries on the matter are dealt with by the following meteorological offices.

**List of Meteorological Offices Available for Telephonic Enquiries**

<table>
<thead>
<tr>
<th>Area</th>
<th>Telephone No.</th>
<th>Area</th>
<th>Telephone No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abingdon</td>
<td>Abingdon</td>
<td>London</td>
<td>Temple Bar</td>
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<tr>
<td>Anglesey</td>
<td>Holyhead</td>
<td>Manchester</td>
<td>Deansgate</td>
</tr>
<tr>
<td>Birmingham</td>
<td>Sheldon</td>
<td>Newmarket</td>
<td>Mildenhall</td>
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<td>Rhose</td>
<td>Norfolk</td>
<td>Narborough</td>
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<td>Cambridge</td>
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<td>Northants,</td>
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<td>Northumberland</td>
<td>Red Row</td>
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<td>Gloucester</td>
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<tr>
<td>Hampshire</td>
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<td>Shrewsbury</td>
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</tr>
<tr>
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<td>Emsworth</td>
<td>Wiltshire</td>
<td>Brackendale</td>
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<td>Huntingdon</td>
<td>Preston</td>
<td>Amesbury</td>
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<td>Lincoln</td>
<td>Louth</td>
<td>Preston</td>
<td>Bawtry</td>
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<tr>
<td>Liverpool</td>
<td>Garston</td>
<td>Preston</td>
<td>Linton-on-Ouse</td>
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</table>

**Table 1**

Average monthly temperatures (°F)

<table>
<thead>
<tr>
<th>Station</th>
<th>County</th>
<th>Average Temperature °F</th>
<th>August</th>
<th>September</th>
<th>October</th>
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<td>Durham</td>
<td>Durham</td>
<td>58.5</td>
<td>54.6</td>
<td>48.6</td>
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<tr>
<td>York</td>
<td>Yorkshire N.R.</td>
<td>60.8</td>
<td>56.7</td>
<td>50.1</td>
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<tr>
<td>Leyland</td>
<td>Lancashire</td>
<td>59.1</td>
<td>55.7</td>
<td>49.7</td>
<td></td>
</tr>
<tr>
<td>Ross-on-Wye</td>
<td>Herefordshire</td>
<td>60.9</td>
<td>57.1</td>
<td>50.6</td>
<td></td>
</tr>
<tr>
<td>Mansfield</td>
<td>Nottinghamshire</td>
<td>60.2</td>
<td>56.3</td>
<td>49.3</td>
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<tr>
<td>Cranwell</td>
<td>Lincolnshire</td>
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<td>57.6</td>
<td>49.8</td>
<td></td>
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<tr>
<td>Cheltenham</td>
<td>Gloucestershire</td>
<td>62.0</td>
<td>57.6</td>
<td>50.6</td>
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<td>Oxford</td>
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<td>62.1</td>
<td>57.9</td>
<td>50.8</td>
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<tr>
<td>Woburn</td>
<td>Bedfordshire</td>
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<td>58.7</td>
<td>49.5</td>
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<tr>
<td>Norwich</td>
<td>Norfolk</td>
<td>60.1</td>
<td>58.1</td>
<td>50.9</td>
<td></td>
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<tr>
<td>Penzance</td>
<td>Cornwall</td>
<td>61.7</td>
<td>59.1</td>
<td>54.7</td>
<td></td>
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<tr>
<td>Plymouth</td>
<td>Devonshire</td>
<td>60.9</td>
<td>58.4</td>
<td>53.4</td>
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<td>Long Sutton</td>
<td>Hampshire</td>
<td>61.3</td>
<td>57.2</td>
<td>50.2</td>
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<tr>
<td>Tunbridge Wells</td>
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<td>61.5</td>
<td>57.6</td>
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<td>Colwyn Bay</td>
<td>Denbighshire</td>
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<td>Inverness</td>
<td>Inverness-shire</td>
<td>56.8</td>
<td>52.9</td>
<td>47.4</td>
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**Table 2**

*Mean deviation from temperature average (°F) in a sample period of 10 years*

<table>
<thead>
<tr>
<th>Year No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<td>Correction</td>
<td>-3.6</td>
<td>-2.0</td>
<td>-1.3</td>
<td>-0.7</td>
<td>-0.2</td>
<td>+0.3</td>
<td>+0.8</td>
<td>+1.2</td>
<td>+1.9</td>
<td>+3.7</td>
</tr>
</tbody>
</table>
Harvesting Methods

Although binders are still used to cut corn, particularly on smaller farms where roots are grown and the corn harvest does not constitute a serious labour peak, the combine harvester method is far the more important and is now used for a very high proportion of cereal crops. The penalty of direct cutting is that at least a proportion of the grain will be at too high a moisture content for storage unless it is artificially dried. An exception to this is when the grain intended for stock feed is stored in air-tight silos. Direct combining is the commonest method of cutting, but indirect or windrow harvesting is still occasionally practised when the crop is markedly uneven in ripeness, due to late or second sowing of parts of the field, and when excessive greenstuff is present. Windrowing may also be used in an emergency when harvesting is delayed and too many fields ripen at the same time.

Direct Cutting

One of the great advantages of combine harvesting, as compared with the binder, is the reduction of man-hours required to clear the field. The reduced risk of loss through unfavourable weather, due to a reduction in the harvesting period, is also of great importance. Although grain losses used to be considered higher with the combine, due to cutting at a later stage of maturity, it is now generally acknowledged that, in most circumstances, a properly adjusted combine will collect significantly more grain than a binder; it can harvest laid crops without much loss and, in addition, standing corn will dry out faster than wet sheaves and the field can be cleared more quickly after harvest—an important advantage on soils which are difficult to work in a wet autumn.

Windrow Harvesting

The crop is first cut by a windrower or swather, or by a binder from which the compressor arm has been removed. The swath is left to dry, lying on a high stubble as long as necessary, before being picked up and threshed.

The technique of windrowing is not always easy to carry out. A standing stubble of 6-8 in. is necessary to support the cut crop and trial and adjustment is usually necessary to determine the optimum cutting height. Laid crops are unsuitable for windrowing. The swath should not be allowed to fall on stubble which has previously been run over by the tractor wheels, so when a binder is used it is essential to offset the tractor hitch sufficiently to ensure that the swath does not slide over into the wheel track depression.

Acreages windrowed at one time should be restricted, because in prolonged bad weather losses are likely to be heavy. A combine harvester pick-up attachment is necessary for collecting and threshing a windrowed crop.

Stationary Threshing

When combine harvesters are used as stationary threshers, the sheaves are fed into the auger or on to the elevator canvas, and must be well shaken out as
with an ordinary thresher. The knife and reel must be removed for safety, and the header platform should be raised to its full height for easy feeding.

Where much stationary work has to be done, it is worth fitting up a temporary feeding table which can conveniently be made of corrugated iron sheeting. The evenness of feed will be improved, thereby increasing output, but outputs on stationary work are usually appreciably less than when the machine is used for direct combining.

**Choice of a Combine Harvester**

N.I.A.E. Users' test reports are now available on many of the commonly used combines and such reports provide an excellent guide to the comparative merits of the machines tested. However, machines are constantly undergoing improvement and particular aspects of design or performance which have been criticized in a report may well have been improved in the meantime.

Combine harvesters may be classified into three groups:

**Self-propelled.** Self-propelled machines have a built-in engine to operate the threshing mechanism and to provide motive power. An outstanding advantage of these machines is that they may be driven straight in at any point without running over the corn; in addition, wet or immature areas in a crop can be kept separate. The operator is situated in a commanding position and is able to assess conditions calling for rapid adjustments of cutting table height, reel position, etc. The range of adjustments provided and their ease and speed of action are important points to look for when comparing machines.

Although drum width in relation to width of cut, drum peripheral speed, straw shaker and sieve area, etc., are all important factors affecting threshing efficiency (and this, of course, applies not only to self-propelled machines), the true potential can only be judged by carefully controlled tests or first-hand experience. The fact that a tractor is not required to pull the machine may be important to many farmers.

**Trailer Machines.** Now that diesel-engined tractors of 35 to over 60 h.p. with 6–12 forward speeds and live power take-off are in common use, the need for a separate engine for a trailed combine harvester is much reduced. Where low-powered tractors are used, and particularly in heavy crops or in hilly areas, the constant speed of the independent engine, regardless of ground or crop conditions, is an advantage.

**Power Take-off Driven.** As a result of power increases in farm tractors and of power take-off refinements, power take-off driven machines are now available with widths of cut up to 10 ft. A tractor which has an adequate reserve of power for normal requirements can, if fitted with an efficient governor, provide for the sudden demands for extra power to maintain a near constant drum speed.

**Other Factors Influencing Choice**

**Tanker or Bagger**

The choice in this case is usually dependent on the facilities available at the farm for handling grain in bulk. Bagger combines are still widely used and
call for the minimum capital expenditure in drying and storage equipment. In addition, small parcels of grain or other seed may be conveniently kept separate. However, bulk handling at all stages, if effectively notably reduce the man hours and the amount of work involved in harvesting, storing and disposal. Grain tank capacity, or more important, the time taken to fill under good harvesting conditions, should be noted and related to the proposed transport arrangements. Levelling augers in the grain tank are now provided on some machines to ensure full use of available capacity.

**Wheel Equipment**

Combine harvesters, particularly the larger self-propelled models, are heavy machines, and in wet harvests, bogging down can be a serious problem. For such conditions the provision of larger section tyres or twin wheels may be an important choice factor.

**Output**

Width of cut is not a reliable guide to combine output. Some of the self-propelled machines now available are capable of operating at much higher speeds than formerly and a change to a new combine of similar width of cut to its predecessor is, therefore, likely to provide a useful reserve of output. Grain drying and reception arrangements, however, must be capable of dealing with this increase, otherwise the machine can only be used effectively when little or no drying is required, or to cut about the same quantity daily as the old machine but when conditions are most favourable over a shorter working period. This latter advantage should not be underestimated.

A modern self-propelled machine should comfortably cut 20 acres per ft of cut per season even in the generally more difficult conditions of the north and west; while in the south and east, 30 acres is normally quite easily attained and commonly exceeded. With less modern machines, particularly of the trailed type, the above guide figures should be reduced by about 20 per cent. Where soil conditions tend to give relatively light crops, a wider cut than would normally be chosen may be justified. When considering cutter bar width, it is important to remember that transport width is invariably greater except where pivoted table assemblies are fitted and although gateways may be widened without much trouble, difficulties may arise in narrow country lanes.

One method of assessing combine harvester output requirement is based on a target period for completion of the harvesting operation in 8-hour working days. The target period is usually a compromise: if it is too short, capital investment may be unnecessarily high, while grain intake arrangements may create difficulties in good harvesting conditions; if it is too long, full advantage may not be taken of brief spells of fine weather in a difficult season. Target harvest period is of course influenced not only by average weather conditions but also by other crops grown on the farm. It may not be vitally necessary for instance to complete the harvest quickly on a mainly cereal farm where labour requirements for autumn work are limited. A suggested target harvesting period for the Eastern Counties is 20 harvesting days.

Fig. 2 illustrates graphically how such calculations may be made. The main problem, apart from choice of a realistic target harvesting period, is to discover the working rate of a particular combine. Test reports give the most
reliable information on this aspect, though care should be taken to refer to overall working rates achieved during the test. Even these will often be higher than are obtained in practice, and they should be regarded as the maximum rates likely over a prolonged period of use.

A combine is correctly set when it is producing the highest practicable output of reasonably clean grain, with a minimum loss of grain on the ground and in the straw. Grain losses increase sharply as straw throughput increases, as Fig. 3 shows. This graph, taken from the report of a comparative field test
of three combine harvesters, typifies this tendency. Up to a certain straw throughput (t/h) losses remain fairly steady but as throughput is increased beyond this critical rate, losses increase disproportionately.

**Combine Harvester Operation**

The best guide to operation of a particular machine should be found in the manufacturer’s operation manual. General guidance is also given in Farm Machinery Leaflet No. 3 (*Combine Harvesters*, H.M.S.O., 6d.).

**Harvesting Herbage Seeds**

Small seeds pose much greater harvesting problems than cereals. The weight of individual seeds may be only \(\frac{1}{6}\) to \(\frac{1}{5}\) that of a wheat kernel, and this is one reason why separation is much more difficult. The main harvesting methods are:

- cutting with a binder; stock ing and threshing direct from the stock;
- cutting with a windrower, a mower or a binder with the tying mechanism inoperative, followed by threshing in the field from windrows or tripods;
- direct cutting with a combine.

If the combine is used as a stationary thresher in the field, one or more tractors fitted with front and/or rear buckrakes and modified to serve as a hand-loaded carrier, provide a quick and easy means of collecting and transporting the sheaves to the machine. The individual sheaves must be fed as evenly as possible to the elevator canvas or feed auger. For safety reasons, the knife and reel must be removed. Where much stationary work is planned, it is worth fitting up a temporary feeding table, using corrugated iron sheeting or similar material. A sheet or tarpaulin under the table ensures that no seed is lost in this area.

Field windrows are more vulnerable to adverse weather than tripods, but labour requirements are much less. Effective draper type pick-up attachments are now available for most combines and these will deal satisfactorily with herbage and small leguminous seed crops, provided bottom re-growth has not been allowed to anchor the crop.

Direct combining is clearly the most labour-saving method of all, but many small seed crops ripen unevenly so that yields of viable seed in such cases may be low. The method is also more suitable for crops which are reasonably free of bottom growth, such as early varieties of ryegrasses, fescues and cocksfoot, than for very leafy crops. To achieve a high rate of seed recovery, the crop must usually be left later than with indirect methods, and this increases the risk of shedding, especially in wet or very windy conditions. Drying is almost invariably necessary where direct harvesting is employed, due to the high moisture content of the seed.

Some growers go over the crop twice with the combine, to reduce the problems of uneven ripening and shedding losses. The first combine operation is timed for when the crop is rather riper than normal for the binder, and the machine set to leave a long stubble and to thresh out only the ripe seed. After a further period of ripening, the swath is picked up and threshed again. After the first operation, however, prolonged bad weather could restrict over-
HARVESTING METHODS

all yield of viable seed to the quantity already gathered. With this method, it is best to sow seed crops in 1.4 in. drills or less, so that the treated swath is less likely to fall on to the ground between drills; it may also be necessary to fit a deflector at the rear of the combine to reduce this danger.

White clover and alsike are not really suited to direct combining unless the crop stands unusually high, but red clover, sainfoin and trefoil can be combined direct when there is not much leaf and the crop is dry. Timothy is also a difficult crop and a second threshing is usually necessary. Very careful timing is essential to achieve maximum yield, because of the progressive ripening of the seed heads.

TRANSPORT OF GRAIN

Introduction of a combine harvester, with a greatly increased output compared with the machine it replaces, can create difficulties with transport if the problems are not anticipated. On test, outputs, under ideal conditions, of over 10 tons per hour have been recorded by 10 ft cut self-propelled machines. Although such outputs cannot be expected for long periods, it may be important to take full advantage of the machines full potential on occasion. When planning transport requirements to permit uninterrupted combining, the time taken for the grain tank to fill, when the machine is operating at its maximum rate, is the first point to determine. For example, assuming a barley crop of 30 cwt to the acre is harvested by an 8 ft cut combine harvester travelling at 3 m.p.h. with a 20 per cent time allowance for corners, etc., it will cut approximately 2.3 acres per hour and deliver $30 \times 2.3 = 69$ cwt into the grain tank per hour. If the tank capacity is 25 cwt it will fill in just over 20 minutes. If the combine is to be kept working without interruption, the trailer(s) must complete the journey to the store in rather less than this time. If four minutes is allowed for manoeuvring at the store and tipping, 16 minutes is left for travelling. The state of the roads and fields traversed obviously affects the average speed on the journey, but assuming a 7 m.p.h. average (8.6 min per mile), the total distance covered in 16 minutes would be rather less than two miles (i.e., one mile from store to combine at its most distant point in the field). Thus, a 30 cwt trailer working continuously would be sufficient to keep the combine fully occupied at this distance.

A 3 ton trailer would save transport tractor time, but the outfit would be idle in the field between alternate tanker fillings. A good compromise is to use a 3 ton trailer and also to set at least one more trailer down in the field, near the combine, so that the latter can easily run to it to empty. This doubles the time available for the journey to and from the store, but sacrifices a little combining time. It is possible to erect a temporary storage area in the field using straw bales or grain in plastic fertilizer bags to form ‘walls’ on a tarpaulin or plastic sheet. Arrangements for quick turn round at the grain store are obviously of great importance, particularly as transport distance increases and grain tank filling time decreases.

HANDLING STRAW AFTER THE COMBINE

The baler used independently is by far the most popular method of dealing with straw left by the combine. Low density presses attached to the rear of
the combine are attractive where low density bales are required, because a separate operation is avoided. However, if trouble is experienced the combine is held up and they are perhaps more suitable for use with medium to low output machines.

With small machines in light crops the use of a straw deflector which puts two windrows into one enables the baler to work more effectively.

If the straw is to be ploughed in, the job is made much easier and more effective if a spreader is fitted to the back of the combine to distribute the straw over the ground. However, a straw chopping attachment or a separate machine for the purpose is an even more effective aid to satisfactory ploughing.
Principles of Grain Drying and Storage

STORAGE CONDITIONS

Ripe grain consists of a living embryo (the germ), a store of food (the endosperm), and a number of protective coatings (bran, etc.). In common with other forms of life, grain gives off heat, water and carbon dioxide as its store of food is consumed. The rate at which grain lives is governed principally by its moisture content, its temperature and the availability of oxygen. Thus it is possible, by adjusting these conditions, to preserve the properties of grain by reducing its life-activity to a very slow rate.

This is generally done by reducing the grain moisture content and temperature to a level suited to the intended period of storage. The storage of damp grain at a low temperature (45°F) is also possible and the application of this method to farm requirements is in process of development. Grain with high moisture content (18-21 per cent) can be kept successfully in an airtight silo, but when so stored undergoes certain changes which render it unsuitable for milling, malting and seed purposes although it is satisfactory for animal feed. (See p. 191.)

The harmful organisms (insects and mites, moulds and bacteria) that attack stored grain are all subject to the general considerations outlined above, and their activity is reduced in dry cool conditions and in most cases when there is a lack of oxygen.

MOISTURE CONTENT AND TEMPERATURE

The development of moulds, bacteria, mites and, to a lesser extent, of insects can be prevented by reducing the moisture content of the grain to a level at which they will not readily grow. It would, however, be uneconomic in practice to reduce the moisture content of the grain to a low enough value (8-10 per cent) where all insect growth is restricted.

The figures given in Table 3 are the recommended maximum moisture contents for clean and undamaged grain stored at a temperature not exceeding 60°F. Where special cooling facilities are available it is possible to store grain at somewhat higher moisture contents (p. 87). The figures in brackets show the lower moisture content levels required for malting barley and for seed grain.

The general effect of grain temperatures above 60°F is to increase the risk of convection air currents being set in motion within a stored bulk of grain with the consequent probability of redistribution of moisture. This in turn may result in areas of relatively high moisture content grain which become centres of heating and progressive deterioration of grain quality. Too high a temperature at a moderate moisture content also leads to spontaneous heating caused by the development of moulds.

Insects and mites will not develop readily if the temperature is below 65°F and cooling grain to 60°F described on p. 83 is a satisfactory means of preventing infestation. To control moulds and bacteria, however, the temperature must be much lower depending on the moisture content of the grain.
Table 3

Maximum grain moisture contents which are safe for storage in Great Britain at 60°F

<table>
<thead>
<tr>
<th>Period of storage</th>
<th>Percentage moisture content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Up to four weeks from harvest</td>
<td>17 (16)</td>
</tr>
<tr>
<td>Until February</td>
<td>15 (14)</td>
</tr>
<tr>
<td>Until April</td>
<td>15 (14)</td>
</tr>
<tr>
<td>Beyond April</td>
<td>14 (13)</td>
</tr>
</tbody>
</table>

A In bulk or in closely stacked bags without turning or cooling by forced ventilation.
B In bags standing upright and freely exposed to the air, or cooled in bulk with forced ventilation or in bulk with frequent turning from a full into an empty bin.

The moisture content is seldom completely uniform throughout a mass of grain and the figures given in Table 3 apply to the wettest part of the grain and not to an average for the bulk.

For moisture contents up to about 20 per cent chilling to 45°F is necessary: at higher moisteres the temperature must be near freezing point. The way in which grain moisture content and temperature are related to a fall in germination and to insect and damp grain (fungal) heating is shown graphically in Fig. 4.

Fig. 4. Relationship of storage temperature and grain moisture content to insect heating, fall in germination (to 95 per cent in 35 weeks' storage) and damp grain (Fungal heating)
INSECT HEATING AND DAMP GRAIN HEATING

It is not always easy to distinguish between heating due to an insect infestation, and damp grain heating caused by moulds. Insect heating can occur in dry grain, but it may raise the temperature and produce enough moisture locally for damp grain (fungal) heating to develop, particularly above the original insect 'hot spot'. A pre-requisite for fungal heating is the presence of grain of high moisture content. Fungal heating may develop, for instance, in grain that has not been sufficiently dried, especially if it has come off the drier without adequate cooling, in grain that has become artificially wetted by rain, or in grain that has had its moisture content increased because of a heavy infestation of insects. Fungus-eating insects may be associated with the moulds of a damp grain hot-spot, even if the more usual stored product pests are absent.

In both forms of heating the temperature is raised to a certain maximum level, above which the development of the insects or moulds cannot proceed, and further rise in temperature ceases. In insect heating, activity ceases at a temperature of about 110°F, whereas moulds can raise the temperature to 140-160°F before they are inactivated. It is sometimes possible in practice, by measuring the temperature, to decide which type of heating is taking place, but as one form is often dependent on or changes into the other, not too much importance should be attached to this aspect.

OXYGEN

Insects, mites and moulds can be controlled by the removal of oxygen, i.e., by airtight storage. The insects or moulds use up the oxygen in the airtight silo and thus kill themselves before they have become numerous enough to cause damage.

EXCLUSION OF CONTAMINANTS

Greenstuff or weed seeds may have a moisture content considerably higher than that of the mass of grain, and if the conveying system concentrates such material into particular spots in a bulk store, local heating may be rapidly set up. Any such centre of local heating can cause serious consequences, because convection currents will soon spread the high-moisture and heating conditions to other parts of the grain mass. It is, therefore, essential to see that all such contaminating material is either removed before storage or, if present only in small quantity, is dried with the grain to a safe moisture content.

Another objection to the inclusion of rubbish in stored grain is the possibility of it collecting in areas having a relatively high resistance to the passage of cooling air, thereby preventing the intended uniform reduction of grain temperature by this method.

MECHANICAL DAMAGE

Grain which has been damaged during combine harvesting is more prone to attack by moulds and insects; mechanical damage to grain may also reduce
germination and it is therefore especially undesirable in malting barley and seed grain.

It will be clear that, if the conditions for the storage of 'dry' grain are allowed to become less rigorous than they should be, the rate of respiration of all forms of life will increase and the resulting heat and water will encourage a further increase in respiration with the possibility of a rapid deterioration of storage conditions. The same close adherence to appropriate recommendations is as essential for the successful holding of damp grain in chilled grain storage.

**Drying Properties**

Since grain is not always harvested at a moisture content which is safe for the intended period of dry storage, it is frequently necessary to reduce the moisture content. This requirement brings into prominence further properties of grain related to the drying process.

As with all other hygroscopic materials, there is a relationship between the moisture content of grain and the relative humidity of the air surrounding it, when steady conditions have been maintained for a long time. This relationship is different at different temperatures but the variation is comparatively small. It also differs according to types of grain, for different varieties of the same type and, for a given sample, it is different during wetting and during drying.

The relative values of grain moisture content and air relative humidity, when they are in equilibrium, are shown in Table 4 and in Fig. 5. As indicated above, the relationship varies under different conditions but that given here has proved to be satisfactory for practical drying applications.

**Table 4**

<table>
<thead>
<tr>
<th>Grain moisture content</th>
<th>Relative humidity of air</th>
</tr>
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<tbody>
<tr>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>10</td>
<td>49</td>
</tr>
<tr>
<td>12</td>
<td>55</td>
</tr>
<tr>
<td>14</td>
<td>62</td>
</tr>
<tr>
<td>15</td>
<td>70</td>
</tr>
<tr>
<td>16</td>
<td>77</td>
</tr>
<tr>
<td>17</td>
<td>82</td>
</tr>
<tr>
<td>18</td>
<td>86</td>
</tr>
</tbody>
</table>

Another characteristic of grain is that some of its most valuable properties can be destroyed by high temperatures. This applies in particular to damage to gluten which is of importance to the baking quality of wheat, and to a reduction in the germination of malting barley and seed grain where even a small lowering of the germination is totally unacceptable in commercial requirements.

The maximum air temperature for drying milling wheats must not exceed 150°F provided the moisture content of the grain does not exceed 25 per cent; if grain has a higher moisture content than 25 per cent the air temperature should be reduced to 140°F.
The sensitivity of grain to germination damage from excessive temperatures depends on its moisture, as shown in Table 5.9

<table>
<thead>
<tr>
<th>Moisture content (%)</th>
<th>Maximum air temperatures for no damage to germination °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>152</td>
</tr>
<tr>
<td>20</td>
<td>142</td>
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<tr>
<td>22</td>
<td>143</td>
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<tr>
<td>24</td>
<td>127</td>
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<tr>
<td>26</td>
<td>120</td>
</tr>
<tr>
<td>28</td>
<td>114</td>
</tr>
<tr>
<td>30</td>
<td>110</td>
</tr>
</tbody>
</table>

In practice it may prove to be very difficult, if not impossible, to carry out proper grain sampling and accurate moisture determinations to allow the
drying air temperatures to be adjusted correctly and frequently to correspond with the variations in the real moisture content of freshly harvested grain.

If there is any doubt concerning the precise moisture content of the grain being supplied to the drier or about the accuracy of the thermometers used for measuring the air temperature, it may be preferable, at times, to use the lower temperatures recommended on p. 50.

Grain to be used only for feeding purposes can be dried at temperatures up to 220°F. In some cases there may be considerable variation in the moisture content in different parts of the grain mass immediately after drying at temperatures of 180-220°F and it is advisable to see that the grain is well mixed and cooled before it can be left safely in long term bulk storage.

METHODS OF DRYING

In a warm dry climate cereal grains dry naturally in the field to a safe moisture content for subsequent storage. In this country the mean daily relative humidity of the atmosphere between the middle of August and the end of October is between 80-85 per cent which corresponds (Fig. 5) to a moisture content of about 17 per cent. Little useful drying could, therefore, be achieved by passing atmospheric air through a bed of grain. Even if air was used only during the less humid times of the day, the process would still be very slow and unpredictable.

The relative humidity of the air can be reduced in various ways but the one which has been found to be the most convenient and economical is by raising its temperature. Reference to a psychrometric chart (Fig. 6) shows for example that air at say 62°F DBT and 85 per cent RH (at point X) must be heated to 70°F to reduce the relative humidity to 60 per cent (at point Y).

Grain driers employing heated air may be grouped into two main categories; those using a small temperature rise, where the moisture content of the grain is brought almost into equilibrium with the drying air; and those working with a considerably higher temperature rise, where the drying process is continued only until the grain has been reduced to the required moisture content instead of being brought to the very low equilibrium value corresponding to the much hotter air. Some other types of driers are operated at temperatures between the lowest and highest.

LOW TEMPERATURE DRIERS

Driers requiring only a small rise in air temperature are those where grain is placed in relatively large quantities for drying in situ either on the floor of a building or in a ventilated silo. The increase in air temperature needed is usually only a few degrees to give a mean daily relative humidity of 60-65 per cent. The recommended depth of grain is 7-8 ft for the floor method, and up to 10 ft when silos are used. Warm air is generally introduced at the bottom of the bed, therefore drying begins at the bottom and progresses upwards until the moisture content of the mass of grain has been reduced to about 14 per cent, i.e. when it is in equilibrium with the drying air. Grain in depths up to about 10 ft can be dried by this method from 20-15 per cent m.c. in 10-14 days using an air velocity of 15-20 ft min. The air emerging
from the top of the grain bed is in a saturated condition for most of the drying period and the rate of drying depends upon the amount of warmed air which is passed through the grain, which in turn may have an economic limit imposed by the power requirements of the fan and air heaters.

Fig. 6. Psychrometric chart showing increase from 62 °F-72 °F dry bulb temperature required to reduce air of 85 per cent r.h. (X) to 60 per cent r.h. (Y)

The method of connecting the air supply to the bottom of a deep bed of grain is not the only possible arrangement; several others have been employed mainly with the object of reducing the effective depth of grain to be dried. Some silos have a central duct with the air passing radially through the grain and the perforated or expanded metal walls of the structure. In other designs air is introduced and extracted through a pattern of horizontal ducts spaced at various levels between the base and the top of the silo.

High Temperature Driers

If air is raised to a higher temperature, its water-carrying capacity is increased, but, since its relative humidity is much reduced, it tends to dry grain to an unnecessarily low moisture content. The drying process, therefore, has to be stopped some time before the grain comes into equilibrium with the drying air and when its mean moisture content is at the desired value. In this case there is quite a steep gradient of moisture content, from a low value at the bottom of the bed to a high one at the top.

In order to prevent the top and bottom moisture content from differing
by too much, the depth of the grain undergoing drying must be kept relatively small and, in continuous driers, the grain may also be mixed as it moves through the machine.

For a given depth of grain the moisture content gradient will be greater for higher air temperatures assuming that the final moisture content is to be 14–15 per cent. Similarly the temperature gradient across the grain bed will be greater at high temperatures.

The rate of drying depends mainly upon the inlet air temperature, and the amount of drying which is carried out at any particular air temperature and initial grain moisture content, is controlled by the time for which grain remains in the drier. The rate of drying is also influenced by the quantity of air passing through the grain bed but in most continuous grain-flow machines this is fixed at an optimum value and is not adjustable as part of the normal drier control facilities.

It is usual to provide a grain cooling section immediately after the drying unit and, except at the lowest temperatures, a significant additional weight of water is evaporated during the cooling stage. It is highly desirable to reduce the temperature of the grain to 60°F but this will not be possible if the ambient air temperature at the time of drying is above this value. In such circumstances the grain must also be cooled in storage.

The high temperature continuous driers can cause damage to grain if they are wrongly operated but machines can be designed to reduce the risk of thermal damage. With continuous driers of the cross-flow type, i.e., where the grain and hot air move at right angles to each other, the hot air supply may be provided in several stages so that wet incoming grain is subjected to a lower drying air temperature than when it has been partly dried. A better method is to use the counter-flow principle where the grain and hot air move in opposite directions. The hot air enters at the end where the dry grain leaves and becomes progressively cooled by evaporation as it encounters wetter grain. These two methods of drying take advantage of the fact, already mentioned, that the sensitivity of grain to thermal damage depends on its moisture content.

The counterflow type of drier also makes the most effective use of the drying air since the air, as it becomes more moist, passes through wetter grain until it leaves the drier more or less in equilibrium with the incoming wet grain and is, therefore, carrying away the maximum possible amount of water.

In ventilated silos the rate of drying is limited by the water-carrying capacity of the air, and the individual grains remain at a nearly uniform moisture content from their centres to their surfaces; but with higher temperature driers, the rate of drying may be limited by the rate at which the grain will part with its moisture. That is, the water may be removed from the outsides of the grains faster than it can be replaced from their centres and the grain may become surface-dry. This can give a false impression of the extent to which drying has been completed.

A possible advantage of high-temperature drying is that the very low moisture content reached by the surfaces of the grains, together with their relatively high temperature, may discourage the development of fungi on, or under, the grain surface and thereby improve the storage properties.
Medium Temperature Driers

Several types of drying systems employ air temperatures which are intermediate between those referred to above, and the methods of drying grain in hessian bags or in shallow rectangular trays can be taken as two examples. 35, 39, 51

In the first of these systems, open weave bags containing the damp grain are placed on apertures in a horizontal platform in such a manner that a stream of warm drying air passes through the grain for an appropriate period. The depth of grain should be 7-8 in. and the airflow is normally about 140 c.f.m. /bag; the temperature rise for the air is 25-30°F and, under these conditions, a drying rate of the order of 1 per cent m.c. reduction per hr can be obtained. This method of drying is safe for agricultural or horticultural seeds as well as cereal grains and where necessary the depth of seeds in the bags can be reduced in order to maintain an adequate flow of air through them.

Higher air temperatures up to 150°F are employed with tray driers and the depth of grain is generally about 2 ft. For cereal grains an airflow of 50 c.f.m. /sq. ft of tray area gives satisfactory results. Because of the relatively thick bed of grain, the moisture gradient at the end of a drying period tends to be considerable and the moisture content of the topmost layer of grain may be only slightly decreased, although the mean value of the whole bed has been reduced to 14 or 15 per cent. The rate of drying will vary, mainly according to the air temperature and airflow employed, but a reduction of 1 1/2 per cent m.c. per hr would be typical.

As with the high temperature continuous flow driers (cross-flow), thermal damage to the grain can be caused by the use of too high air temperatures and the recommendations on p. 50 must be applied.

Other Systems of Drying

Other methods of drying than those outlined above have been proposed. For example, the grain itself might be heated by exposure to infra-red radiation or by means of high-frequency electrical energy, instead of by the passage of preheated air.

The relative humidity of moist air could be reduced by removing water from it as an alternative to simply raising its temperature. Thus the air supply might be passed over a drying agent, such as silica gel, or it might be cooled to a temperature where the water vapour condenses and is removed as a liquid.

These and various other systems offering a possible alternative to drying with heated air, involve increased capital cost and complication of equipment and they are seldom encountered in practical form on the farm.

Resistance to Airflow

Among the various physical properties of cereal grains, which are relevant to matters concerning drying and storage procedures, is that of their resistance to airflow when being dealt with in depths which may be from 4 in. in a continuous flow drier to 10 ft in a ventilated silo. In most cases the resistance of
the grain forms the largest part of the total resistance of the system to which the fan is supplying a flow of air.

The curves in Fig. 7 have been taken from various sources\textsuperscript{10, 39} and are shown as a guide to relationship between static pressure and airflow for cereal grains, and for several different kinds of seeds. The figures represent the resistance to airflow for a bed depth of 1 ft and for material which is uniformly dry and clean. For the present purpose it can be assumed that the resistance increases and decreases in direct proportion to the bed depth (i.e., for 6 in. it will be half that shown, or for 2 ft it will be double, etc.).

Some variation in the resistance of grain and seeds must be expected in practice, and this may be especially evident with different moisture contents and bulk densities and also with any artificial packing of the bulk material, due to the manner in which it has been loaded into a silo or drier. The presence of dust, shrivelled grains, weed seeds, straw, and other foreign matter, may also cause a change in resistance compared with a clean sample.

The data in Fig. 7 cannot be applied directly to finding the resistance of grain in a radially ventilated silo\textsuperscript{27, 54} nor does it represent the resistance of grain and seeds in sacks.\textsuperscript{61}
Choice of Drying System and Planning of Installations

CHOICE OF DRYING SYSTEM

The choice of drier for a given farm is not a subject on which it is possible to lay down any precise rules. The drying problem depends on:

- the climate, which differs materially from season to season, but is generally less favourable in the north and west of Britain than in the south and east;
- the acreage to be harvested, and crop yields;
- the combine strength available for dealing with the harvest;

Choice of drying equipment will also depend on:

- farming policy regarding the proportions of the crop to be sold as soon as possible, or to be stored for later sale, or for feeding;
- existing facilities at the farm, and the need to consider any associated problems such as grass or hay drying, corn-grinding and other food preparing equipment, buildings available, etc.;
- the amount of capital that can be invested.

The fundamentals of drying are the same, whatever drying system is used, the main practical differences between the various systems being in the manner and ease of handling the grain and the speed at which drying takes place. Some driers are designed to remove the excess moisture in a matter of hours, while other systems may take several days to remove small amounts.

Clearly the first step must be to define the size of the drying problem, by estimating the amount of grain that will normally need to be dried and the average amount of moisture that it will be necessary to extract from it. Having done this, the answer can be compared with the known performances of the various types of driers, some of which are briefly summarized in the following pages.

SIZE OF THE DRYING PROBLEM

The amount of drying that needs to be done in relation to the size of the harvest varies considerably according to geographical location, organization of the harvest, and the individual season. The wise farmer plans so as to be able to deal with the most difficult conditions likely to be encountered; but it is usually far too expensive to equip to such an extent that this is achieved, without some difficulty, in the wettest and latest harvest. Generally speaking, however, it pays to be in a position to proceed with the harvest in spite of bad weather, rather than to be so ill-equipped that it is always necessary to wait until grain is fairly dry. Whereas ten years ago it was often argued that a drier was unnecessary on farms with plenty of combine harvester capacity, a number of wet harvests and the increasing effectiveness, efficiency and economy of driers have now made such an attitude completely untenable. On the contrary, it is unwise and generally too risky to attempt to secure the harvest without using a drier. No serious attempt has ever been made to
arrive at the average amount of drying that needs to be done: since this fluctuates enormously from year to year any such assessment would be of little value. With these reservations, the figures in Table 6 give some indication of typical grain moisture contents at harvest in average (1948 and 1960) and very dry seasons (1949 and 1961) in the eastern counties in the general neighbourhood of Silsoe, Bedfordshire. The figures refer to samples taken at random during combining, and indicate the proportions of samples falling in various moisture content groups.

Table 6
Grain moisture content at harvest. (E. Counties, average and very dry seasons)

<table>
<thead>
<tr>
<th>Range of moisture content per cent</th>
<th>1948 All cereals</th>
<th>1949 All cereals</th>
<th>1960 Capelle wheat</th>
<th>1961 Proctor barley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 14%</td>
<td>0.5%</td>
<td>22%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14-15.9%</td>
<td>5%</td>
<td>31%</td>
<td>2%</td>
<td>16%</td>
</tr>
<tr>
<td>16-17.9%</td>
<td>26%</td>
<td>26%</td>
<td>29%</td>
<td>45%</td>
</tr>
<tr>
<td>18-19.9%</td>
<td>25%</td>
<td>11%</td>
<td>32%</td>
<td>16%</td>
</tr>
<tr>
<td>20-21.9%</td>
<td>26%</td>
<td>4%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>22-23.9%</td>
<td>8%</td>
<td>3%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>24-25.9%</td>
<td>6%</td>
<td>2%</td>
<td>6%</td>
<td></td>
</tr>
<tr>
<td>26-27.9%</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28-29.9%</td>
<td>1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 and above</td>
<td>0.5%</td>
<td>1%</td>
<td>1%</td>
<td></td>
</tr>
</tbody>
</table>

The percentage in high moisture groups is appreciably higher in a wet season such as 1965, or in regions of high rainfall.

CAPACITIES AND GENERAL CHARACTERISTICS OF DRYING SYSTEMS

Continuous Driers

The principal advantage of continuous driers is that most grain can be dried safely within a few hours of combining (subject to the qualifications discussed in the following pages) and the worry of ensuring that grain in store is safe, is more or less localized. Continuous driers are particularly suited to districts where damp conditions often prevail at harvest, as they are less affected by the humidity of the air than are types of driers working with a low temperature rise.

Most continuous farm driers are rated at capacities ranging from 1-5 tons per hour, although higher capacities (e.g., 10 tons per hour) are also available. These ratings refer to the output when drying wheat by 4, 5 or 6 per cent (usually 5 per cent from 21 per cent), using a hot air temperature of 150°F. Actual output obtained depends on the hot air temperature used, the amount by which the moisture content is to be reduced, and to some extent on the type of grain dried (see p. 50).
Some farmers prefer to minimize management problems by choosing a larger machine than is really essential. On account of capital cost, however, it is usually inadvisable to choose a continuous drier with a rated capacity equal to the maximum hourly output of the combine harvester(s), since the drier can, if necessary, work much longer hours than the combine. Moreover, the output of the combine is normally low during periods when the grain is specially damp, and maximum combine output usually occurs when grain needs little or no drying. In general, a continuous drier, with a genuine rating of 2 tons per hour, should be capable of dealing with 100 tons of grain per week without the necessity of working at nights or weekends. This size of drier will, therefore, be adequate for quite large farms even where all the grain needs drying. Driers of 5 tons per hour capacity, or more, are needed only on very large farms or in extremely unfavourable conditions, where a high proportion of the grain needs double drying to bring it to a storable condition.

The seasonal output from a drier of a given size depends to a considerable extent on the facilities provided for grain handling. Bulk handling is the only logical solution for a farm with a small staff, and for good results it is essential to arrange the installation so that drying can proceed for long periods with only push-button control. Adequate self-emptying pre-drying storage, matched to combine and drier capacity, is an important requirement; e.g., if combine capacity can reach 8 tons per hour and drier capacity is 3 tons per hour, the aim should be to provide a minimum of about 40 tons of self-emptying pre-drying storage, so allowing the combine to work at full capacity for 8 hours without any grain intake difficulties. In such circumstances, the drier may need to run for up to 16 hours daily. If weather conditions continue favourable, so that the combine can work long hours for several days in succession, grain moisture content at combining is likely to be low, and it should be possible to push up drier output to at least 4 tons per hour. However, the farmer who wants to avoid running the drier for more than about 14 hours a day, or who is in a region where climatic conditions are normally adverse, could in such circumstances be justified in choosing a drier of 5 tons per hour capacity.

A factor which must be borne in mind is that it is generally unwise to leave continuous-flow machines entirely unattended, even when they are delivering the grain direct to bulk storage. Quite apart from the possibility of failure of elevating or conveying equipment, present-day machines are by no means automatic as regards production of a uniform final grain moisture content when, as normally happens, the moisture content of incoming grain is continuously changing. It is, therefore, necessary to arrange for fairly frequent supervision, and in these circumstances it is not worth while to use a very small (e.g., less than 1 ton per hour) continuous-flow drier. For such reasons, drying in bulk or in batch is often preferable, especially for small farms, where only one or two men are available for the whole of the harvesting operations.

**Tray and Other Batch Driers for Loose Grain**

Batch driers for loose grain (e.g., sloping tray driers, simple ducted driers, small-diameter radial-flow driers) are well suited to the needs of mixed farms
in wetter districts. They enable the drying to be done quickly, with the certainty of preserving grain quality; and, where well installed, with a minimum of labour and supervision. Drying capacities may be easily calculated from the performance figures on p. 60. A typical tray with grain 2 ft deep, an air flow of 50 c.f.m. per sq. ft, and working at a temperature of 120°F, will take about 5 hours to remove 6 per cent. In adverse conditions it will dry three batches daily, one being left on overnight. For easy operation, it is desirable to provide hoppers of similar capacity to the drier for holding grain both before and after drying. This makes it possible to change over with a minimum of delay and labour.

Batch drying is essentially a medium-temperature, medium-speed system, with lower temperatures and a longer drying time than continuous-flow dryers but a higher temperature and much shorter time than a bulk drying system. Typical temperatures are about 100–120°F. Drying is not taken to the equilibrium point, but must be stopped when the top is slightly under-dried and the bottom slightly over-dried; the grain being mixed during emptying in order to secure uniformity.

There is no sharp dividing line between a large-capacity batch drier and drying grain in bulk. The only real difference is in the method of use. For example, a radial-flow drier can be used as a batch drier, using a moderate (e.g., 25°F) temperature rise and subsequent mixing; or it can be used as a storage drier, with air only warmed sufficiently to bring grain moisture content into equilibrium with the relative humidity of the drying air. (See p. 78.)

**Platform Driers**

Platform driers for grain or seed in sacks can be very suitable for farms where bulk handling is unnecessary, or impracticable on account of equipment and facilities already on the farm. The method is particularly suited to small farms, where the grain is harvested in sacks by a contractor, and to farms where seed crops, such as herbage seeds, are grown in fairly small quantity. A medium-sized installation, with about 50 apertures and an oil-fired drier unit burning about 1 gallon per hour, will reduce the moisture content of the 50 cwt batch from 21 to 15 per cent m.c. in about 6 hours. Its drying capacity is, therefore, comparable with that of a continuous-flow drier of about 8 cwt per hour capacity. This, at first sight, seems very little, but such driers can do 50 tons a week, and this is adequate for most small farms. Much smaller sizes, electrically operated (e.g., 3 per cent m.c. removal per hour from 30 cwt) are, in fact, quite big enough for many small farms.

**Dual-purpose Batch Driers**

Though a small platform with an electrically operated unit suits some farmers, there is much to be said for a larger batch since the quantity of grain combined is often the produce from several acres, and it is a great convenience if this can be handled as a batch. This is practicable on a suitably designed dual-purpose hay/grain drier. Here the floor is usually constructed of 3 X 3 in. 5 gauge welded mesh supported on a framework of timber. The partly-filled sacks are laid all over the floor, 2–3 layers deep. By this means a single bay, with an area of 450 sq. ft, can hold up to about 20 tons of corn.
CHOICE OF DRYING SYSTEM

Chief disadvantage of the method is the labour involved in handling the corn on and off the drying floor; but the system suits the farm where hay drying is important and only a little corn drying is needed.

DRYING AND STORAGE IN BULK

Drying grain in bulk, whether in a silo or on the floor, is essentially a slow-drying system. It involves using a large volume of air only slightly warmed, with drying continued over a very long time. One of the most frequent mistakes made by farmers, who have not already become accustomed to drying in bulk, is to expect drying to be completed far too soon. A typical average rate of moisture removal, where full drying capacity is concentrated on a particular bulk of grain, is $\frac{1}{2}$ per cent per day; so grain which is to be dried from 21–16 per cent m.c., must be blown for a total time in the region of 10 days. This is usually no great disadvantage, but it has to be understood that the time is not only long, but is influenced by atmospheric conditions much more than is the case with higher-temperature drying systems. The water evaporative capacity of a well-designed plant for 150 tons of bulk storage is normally equivalent to that of a continuous-flow drier rated at rather less than 5 cwt per hour; but this capacity is adequate for the need, provided that initial moisture content is within reasonable limits and the equipment is properly operated. In general, vertical air flow ventilated bins are best suited to conditions where not much of the grain is normally harvested at over about 21 per cent m.c., and where the harvest is reasonably early. This applies both to ventilated silos and to drying grain on the floor. Ducted or radial air flow ventilated bins, in which the air is required to flow only a short distance through the grain, are more suitable for dealing with grain of higher moisture content. For really adverse conditions it is better to choose a higher temperature quicker-drying method, e.g., a batch drier or a continuous-flow drier.

Important advantages of systems of drying in bulk include (a) ability to receive grain from the combine at an almost unlimited rate, and (b) the fact that the drier can operate completely unattended, apart from an occasional check, and adjustment if necessary.

Where conditions are suited to storage drying, and this applies to most of the main corn-growing areas of Britain, there is the problem of choosing between single-purpose grain silos and drying on the floor in a general-purpose building. There is something to be said for both methods. In general, drying and storing in silos can have some technical advantages. The various parcels of grain are under more positive and independent control; they are less accessible to vermin; and provided the silos are all ventilated and equipped with sweep-arm auger unloading, filling and emptying requires less attention and ingenuity. Against this must be set the fact that a fully equipped specialized system is likely to involve a higher capital cost, and is useless for most other agricultural purposes, whereas a well-designed floor store can be efficiently used, if necessary, for a variety of purposes. Even while partly filled with grain, such buildings can provide useful storage space for fertilizers and implements, and, when empty, the building and equipment can be used for conditioning baled hay. Moreover, in the long term, if enterprises on the farm are changed, general purpose buildings may be used for such
diverse purposes as bulk storage of potatoes or for housing almost any of the common types of livestock. It is, therefore, with good reason that this type of store has rapidly become popular.

**High-moisture Grain Storage**

Choice of a drying and storage system needs to take account of the possibility that at least a part of the harvest might be better stored without drying. The various methods of high-moisture storage are described on pp. 87-97.

**Air-tight Storage**

Many farmers who already have adequate equipment for drying, but would like more storage capacity for grain which is to be used for stock feed, are likely to find that high-moisture storage for this additional capacity fits in well. The air-tight storage is unlikely to be much more expensive than corresponding storage for dried grain, and any extra capital cost is balanced by avoiding the cost of drying, and greater ease of managing the harvest. A complete switch to large-scale air-tight storage, on the other hand, can probably only be justified where a suitable specialist large-scale stock enterprise is being established. In such a case, some careful calculations are needed, and it would seem wise, in the present stage of knowledge, to arrange to 'write off' the capital cost of the silos in a fairly short time, and also to consider what use can be made of them for other purposes, if it should prove that high-moisture grain storage is not as sound as it appears at present. Subject to this consideration, air-tight storage appears to be a sound method of storage where large quantities of barley have to be fed throughout the year.

**High-moisture Storage in Unsealed Silos**

Insufficient information is available to permit a full assessment of the possibilities of storing wet grain for stock feed in silos which are sealed only by a plastic sheet, and which remain unsealed after unloading begins, the grain being removed from the top by an unloader similar to those used for unloading silage. Possible advantages of this method of storage are:

- it may be, but is not necessarily, cheaper than storage in an air-tight silo;
- the silo is of a type which can equally well be used for high dry-matter silage, so is somewhat more 'dual-purpose' than the air-tight type;
- this type of silo and unloading method fits in with a very early harvest, and this may be desirable for such reasons as securing a level seasonal distribution of labour requirements, or to facilitate the control of wild oats.

The unsealed type of silo is clearly unsuited to farms where the grain is only required intermittently or at a very slow rate. It appears to fit in best where there is a heavy demand for high-moisture barley during the period extending from early autumn to late spring.

**Cooling High-moisture Grain with Chilled Air**

As explained on p. 87, grain may be kept at moderately high moisture content for a variety of purposes if it is quickly cooled to a sufficiently low temper-
There are clearly advantages in the practice where the grain is needed for use at the moisture content at which it is stored. Thus, if grain is needed for a particular purpose (e.g., seed, milling or malting) at say 18 per cent moisture content, there is a good deal to be said for avoiding drying merely in order to keep it. When the necessary floor storage or bins are available, capital cost of the equipment for chilling is not high (not more than about £2 per ton), and since running cost of the equipment is very low (e.g., less than 1s. per ton per month) the economics of the method of storage can be attractive.

Experience of the process on farms indicates that the technique may have an important future, but that, before deciding to apply the method, farmers should make sure that potential buyers of the grain are willing to accept and appreciate grain stored by this method.

**Capital Cost and Economics of Drying and Storage**

In comparing the capital costs of the drying systems whose capacities have been briefly surveyed in the previous section, it is necessary to take account of the fact that storage drying systems provide for both drying and storage of an appreciable proportion of the harvest. Such systems will not, therefore, usually be chosen unless storage of the grain for an appreciable time is a primary consideration. The cost of a ventilated bin drier is necessarily high compared with, say, a batch drier, on account of the fact that an appreciable amount of storage is bound to be provided. The bulk storage capacity needed should, therefore, be the next important consideration after the drying capacity required has been estimated. The provision of storage in itself is often not very costly, but most bulk storage systems also necessitate grain-conveying systems, and it is the combined cost of storage and conveying that makes some installations expensive.

Continuous driers, because of their greater complexity compared with the simple batch types, tend to be more expensive, but some of the small continuous driers (20-30 cwt per hour), together with simple storage, do not cost very much more than the size of ventilated silo installation needed to provide the necessary drying capacity.

For a farmer who has storage capacity for grain in sacks, and wishes to provide himself with a safe and efficient grain drier at the smallest possible cost, the platform drier is worth consideration. If properly planned, installation of this type of drier need not lead to any further expenditure, and it provides insurance against an unfavourable season.

Table 7 shows examples of capital costs for typical drying and storage equipment installed in the years 1963-64. The figures given are rounded-off averages of a small sample of installations which were typical of the plants installed in those years. Much lower figures are possible for some types of installations using large bins, both floor-ventilated and radially ventilated; but in practice examples of the low costs sometimes claimed were rare.

The seasonal price increase for wheat helps to cover the costs involved in grain drying and storage on the farm. With barley, the position is problematical; the price fluctuations do not follow a regular pattern. Owing to the rapid increase in the numbers of farm grain driers in recent years, the pressure on the grain market immediately after harvest has eased somewhat, but it
<table>
<thead>
<tr>
<th>Type of drier</th>
<th>Storage</th>
<th>Conveying</th>
<th>Ancillary equipment</th>
<th>Tons dried annually</th>
<th>Tons stored annually</th>
<th>Total capital cost*</th>
<th>Capital cost per ton stored*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform, 2 tons all-electric</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>50</td>
<td>—</td>
<td>250</td>
<td>5</td>
</tr>
<tr>
<td>Tray, 2 tons oil-fired</td>
<td>None</td>
<td>Mobile augers</td>
<td>None</td>
<td>150</td>
<td>—</td>
<td>750</td>
<td>5</td>
</tr>
<tr>
<td>Floor-ventilated bins all-electric</td>
<td>Rectangular galvanized steel</td>
<td>Bucket elevator chain and flight conveyor</td>
<td>Cleaner</td>
<td>300</td>
<td>250</td>
<td>4000</td>
<td>16</td>
</tr>
<tr>
<td>Floor-ventilated bins gas-fired burner</td>
<td>Outdoor cylindrical galvanized steel</td>
<td>Large-capacity augers</td>
<td>Bucket elevator chain and flight conveyor</td>
<td>300</td>
<td>250</td>
<td>3000</td>
<td>12</td>
</tr>
<tr>
<td>Radially ventilated silos all-electric</td>
<td>Indoor cylindrical expanded metal</td>
<td>Bucket elevator chain and flight conveyor</td>
<td>Cleaner</td>
<td>300</td>
<td>250</td>
<td>4000</td>
<td>16</td>
</tr>
<tr>
<td>Continuous 1½–2 tons/hr</td>
<td>Rectangular galvanized steel</td>
<td>Bucket elevator chain and flight conveyor</td>
<td>Cleaner</td>
<td>400</td>
<td>250</td>
<td>5000</td>
<td>20</td>
</tr>
<tr>
<td>Continuous 2½–4½ tons/hr</td>
<td>Rectangular galvanized steel</td>
<td>Bucket elevator chain and flight conveyor</td>
<td>Cleaner</td>
<td>500</td>
<td>300</td>
<td>5400</td>
<td>18</td>
</tr>
<tr>
<td>Continuous 5 tons/hr</td>
<td>Rectangular galvanized steel</td>
<td>Bucket elevator chain and flight conveyor</td>
<td>Cleaner</td>
<td>800</td>
<td>600</td>
<td>9600</td>
<td>16</td>
</tr>
<tr>
<td>Continuous 5 tons/hr</td>
<td>On-floor</td>
<td>Mobile augers</td>
<td>None</td>
<td>800</td>
<td>600</td>
<td>6000</td>
<td>10</td>
</tr>
<tr>
<td>In bulk on floor</td>
<td>On-floor</td>
<td>Mobile augers</td>
<td>None</td>
<td>200</td>
<td>200</td>
<td>1800</td>
<td>9</td>
</tr>
<tr>
<td>In bulk on floor</td>
<td>On-floor</td>
<td>Mobile augers</td>
<td>None</td>
<td>400</td>
<td>400</td>
<td>3200</td>
<td>8</td>
</tr>
<tr>
<td>In bulk on floor</td>
<td>On-floor</td>
<td>Mobile augers</td>
<td>None</td>
<td>800</td>
<td>800</td>
<td>6400</td>
<td>8</td>
</tr>
</tbody>
</table>

* Except where otherwise stated, includes building costs after deduction of grant under Farm Improvement Scheme.
† Excludes any new building costs.
should be remembered that it is after the most difficult harvest that this pressure tends to be greatest and it is in such seasons that the farmer with his own drying and storage facilities is in a strong position.

Factors which are sometimes overlooked in assessing the pros and cons of farm drying and storage, are the amount of capital tied up in stored grain and possible reductions in returns as a result of over-drying.

Fuel and power costs of grain dryers usually tend to be of minor importance compared with the costs that arise from capital expenditure. They may be easily calculated on the following basis:

- in an oil-fired continuous-flow or batch drier, 6 per cent m.c. removal (from 21 to 15 per cent) from 1 ton of grain requires about 24 gallons of diesel oil and about 8 units of electricity for driving fans. With oil at 15.4d. a gallon and electricity at 14d. a unit, the cost is 48.4d. per ton;
- in an electrically operated storage drier, the same performance requires on average about 80 units of electricity, and at 14d. a unit this would cost about 105d. per ton.

This difference in favour of oil firing may be important on a big farm, but it should be remembered that, if a £2,000 oil-fired drier is written off in 10 years and dries only 400 tons a year, depreciation costs £\frac{2000}{10 \times 400} = 10s. per ton. This serves to emphasize the fact that on many farms depreciation is higher than the cost of fuel and power.

**POWER SUPPLY**

Where electricity is available, it is nearly always advantageous to employ it for providing power and light, whatever type of grain-drying or handling system is contemplated. It has so many advantages compared with alternative methods, that the latter are usually not worth considering. Whether electricity should be employed to provide the heat for drying depends on the drying system chosen. In general, it is technically very suitable for use in a storage drying installation for reasons of ease of accurate control and minimum requirement of attention. In high temperature driers, such as continuous driers and some tray types, its use as a source of heat cannot be recommended. Wherever electricity is to be employed, careful planning of the installation is essential, otherwise both the initial cost and subsequent running costs may be unnecessarily high. The electricity supply authorities should be consulted at an early stage of planning, so that they can assist in securing an economic installation. An important point which can influence the choice of drying system is the maximum demand for electricity.

A new grain-handling installation will necessarily increase the maximum demand of the farm for electricity, and this may result either in increased capital charges for the supply of power, or in changed tariff, or both. If the maximum demand is greatly increased, it may involve the provision of transformers of higher capacity, and possibly the provision of a 3-phase supply where hitherto single-phase has been adequate. It may often be possible to provide an extra 10 kW without difficulty, whereas increasing the maximum demand by, say, 50 kW may necessitate major alterations on the supply side. It is always important to keep the maximum demand as low as possible, and
this factor will sometimes be decisive when the relative merits of such things as pneumatic and mechanical conveyors are being considered.

Electrical supply considerations may sometimes be decisive in influencing a choice between two distinct types of drying system. For example, an electrically-driven oil-fired tray drier requires only 4 kW, while an all-electric drier of comparable capacity requires about 48 kW, and an all-electric ventilated silo installation of about 150 tons capacity usually needs about 20-30 kW. The oil-fired drier can be introduced without much disturbance to electrical supply, but the provision of an additional 50 kW may be difficult or quite out of the question.

Further information on alternative forms of heating is given on p. 98.

DETAILED PLANNING OF INSTALLATIONS

The detailed planning of drying, cleaning, conveying and storage layouts depends on the buildings and the equipment that are to be used. Most of the important planning details are referred to elsewhere in the Bulletin, in connection with individual layouts or individual items of equipment. The general guidance given in this chapter should, therefore, be supplemented by more details where necessary.

Adequate planning requires first a choice of system and then a choice of equipment, which cannot be determined until plans linking the various items of equipment have been prepared. With a complicated installation, omission of the preparation of scale drawings is likely to lead to much trouble and cost in assembly, and often to unsatisfactory operation which is subsequently very difficult to remedy.

One of the most important considerations in planning is to decide the general lines of flow of materials through the plant. In many instances, the ideal to be aimed at will be a plant which:

- allows for grain from the combine harvester to enter in an uninterrupted flow at one end of the plant;
- provides the necessary storage for grain which is to be kept for feeding or for later sale;
- permits easy sacking-off or bulk loading of the grain to be sold;
- provides easy intake and storage of bought-in feeds, simple conveying of stored grain to a food-preparing plant, and easy handling of the animal feedingstuffs which will be prepared.

All this involves careful consideration of floor levels, so that everything can be efficiently handled with the use of a minimum of mechanical equipment.

ROAD AND FLOOR LEVELS

An ideal arrangement is possible where there is a slight slope in the land, which permits grain to be delivered to the plant at the general floor level, and the loading out of grain and meals on to vehicles which have the vehicle platform either at floor level or below it. Where the general slope of the land does not give the assistance, these objects may sometimes be achieved by making a sunken road for loading off, or by arranging the conveying equipment to deliver the grain and/or meal to an elevated loading platform.
Both continuous-flow and batch driers for loose grain need adequate storage capacity for damp grain, so that they can be supplied from this pre-drying storage, and the work of drying can continue uninterrupted throughout the night when necessary. With bag-handling combines, the grain-receiving pit need not be very large if adequate storage for grain in bags is available adjacent to the grain pit. When bulk-handling combines are employed, it is usually convenient to provide a wet-grain pit of about 10 tons capacity, or alternatively to provide ample pre-drying storage by installing a smaller receiving pit and raising the grain from this pit to an elevated self-emptying storage bin of the required capacity. It is often convenient to feed the pre-drying bin by means of the overflow from the drier feed.

Recommendations for the construction of wet-grain pits are given on p. 43; attention must be paid to the difficulties that will arise in situations where there is a high water-table. In the early days of bulk handling in Britain it was considered almost essential to be able to run vehicles over the top of the grain-receiving pit, and many farmers still consider this facility worth while, even if it involves building a ramp. The development of efficient hydraulic tipping trailers has, however, removed the necessity for run-over pits on many farms, and there are often advantages in locating the wet-grain pit beneath the main roof, the grain being tipped into it over a dwarf wall.

On large farms, especially where more than one combine is employed, there may be a considerable advantage in having the wet-grain pit divided, to facilitate changing over from one crop to another.

With ventilated bins, the damp-grain pit need not be very large, since the only bottleneck in emptying it is the capacity of the cleaner and of the conveyors. It is often preferable to choose high-capacity cleaning and conveying equipment, and a pit of moderate size, especially if there is the difficulty of a high water-table.

When a new installation is being planned, it is an advantage to site the grain receiving pit inside the building, and to leave a good area of unimpeded floor space near it, so that in emergency, grain can easily be tipped on the floor and pushed into the pit later. Where there is a high water-table, a long shallow V-shaped pit with an auger in the bottom may be most suitable.

**Cleaners**

Choice and layout of the cleaning equipment will depend on the crops grown and on the use to which these crops are to be put, as well as on the attributes of the various types of cleaners themselves. On some farms it is usually possible to combine corn crops in almost as good condition as when a stationary thresher is used, but on others there are frequent difficulties with dirty grain samples, and in such circumstances the provision of good cleaning equipment is essential. There is considerable difficulty in deciding on the need, or otherwise, for providing a cleaner in some simple modern storage drying installations, especially those where the grain is dried on the floor. Introduction of a cleaner interferes with the essential simplicity of the installation; it adds appreciably to the capital cost, but an even greater disadvantage is that it introduces a hindrance to easy and rapid emptying of trailers, and calls for
supervision which it may be difficult to provide. Most farmers are, therefore, justified in taking the view that it is best to look after pre-cleaning problems by growing clean crops and doing a good job of cleaning with the combine.

However much cleaning is done before the grain is put into store, there is certain to be dust when the grain is moved after drying. Where the grain is poured into a bulk transport vehicle direct from a floor-store, the result may be an extremely dusty atmosphere. The best methods of overcoming this problem have still to be worked out, but it seems likely that the ultimate solution will be a powerful controlled suction applied at the intake and exit of the conveyor. The general problem of dust control is further discussed on p. 40.

In considering the location of cleaners, it is essential to bear in mind the need to provide facilities for observing and adjusting the cleaner and for getting rid of the cleanings, as well as for easy disposal of the grain. Chaff and dust can sometimes be conveniently blown straight out of the building, while in other circumstances dust-collecting socks are necessary. Heavy materials removed by cleaners usually need to be collected in bags or boxes, which must be located in positions where emptying is reasonably easy.

Failure to provide for easy removal of cleanings and changing of sieves is a common mistake which results in an untidy plant, unnecessary contamination of cleaned grain, an unpleasant and unhealthy atmosphere whenever the plant is at work, and possibly the development of insect and mite pests.

LOADING OUT IN BULK, SACKING-OFF AND WEIGHING

Loading out of grain in bulk should be allowed for in the design of all modern installations, since this is already an established procedure. This may be achieved either by providing an overhead hopper which can feed grain into road transport vehicles by gravity, or by providing a conveying system which can deliver grain out at some 20 tons per hour. With a continuous-flow drier, provision of adequate self-emptying pre-drying storage can also help to provide a neat solution of the problem, the grain for loading out being placed in one of the self-emptying silos. Provision of a capacity of 20 tons per hour in the bottom conveyor allows for full flexibility, so that grain can be delivered out at a high rate from any silo. Where a farmer wishes to weigh his grain before delivering it in bulk, the best arrangement is to use an automatic weigher through which the grain flows before it is delivered to an overhead hopper. Overhead hoppers should be made to accommodate large road transport vehicles.

Where it is necessary to load out grain in sacks, sacking-off and weighing should be arranged to take place as near as possible to the sack-storage space, and it is essential to avoid having too restricted a space for these purposes. Sacking-off should never be arranged to take place at the foot of an incline so that each sack has to be lifted; a slight slope away from this point is better.

Where the layout permits, it may be more satisfactory to arrange to have the weighing machine immediately beneath the sacking-off hopper, so that the extra movement of wheeling the unweighed sacks to the weighing machine is avoided. This necessitates having the sacking-off hopper fairly high, which is not always practicable. The alternative is to have a double-sack hopper and to have the weighing machine at right angles to this, and
slightly offset. In either case it is convenient to sink the weighing machine slightly into the concrete, so that the platform is at floor level when it is depressed. There should always be enough space to store several tons of grain in sacks at or very near the sacking-off point, and as indicated earlier, it is better if the floor level is at least as high as that of the vehicle on to which the grain will be loaded.

### Conveying Systems

Certain types of grain-conveying systems are briefly considered in conjunction with particular layouts on p. 47 and p. 139, while the conveyors themselves are described in some detail on p. 105. The layouts of complicated installations and conveying systems are naturally interdependent, and it is important to understand the capabilities and limitations of the various conveying systems before beginning the detailed planning of installations.

It must be remembered that the conveying equipment at typical farm plants is little used compared with that in provender mills, and for this reason it is usually important to keep expenditure on it within reasonable limits. It is often more economic to have a cheap system, which involves spending a little time in adjustment or operation, rather than an expensive system which is almost or fully automatic in operation.

Choice of a conveying system will necessarily be influenced by any limitations imposed by the layout of intake hopper, drier, cleaner, storage silos, method of loading out in bulk, sacking-off point, and location of the food-preparing plant. It will also be necessary to consider the necessity to turn grain from one silo to another, and to return it for re-drying or further dressing. Factors such as the need to keep grain samples absolutely pure for seed purposes will have to be considered, and this may influence the choice of conveying system, and in turn the general layout of the plant.

### Food-preparing Plant

The installation of a grain-drying and storage plant will frequently necessitate a rearrangement of the facilities for grinding and mixing of animal feeding-stuffs, and an ideal arrangement is often possible by locating the food-preparing section at the end of the silos furthest from the wet-grain pit and grain drier.

In the past, it has been customary to arrange food-preparing plants on two floors, and this may still be convenient where a good existing building with two floors is available. There is, however, no good reason to build new two-storey buildings since, with modern equipment, including as it does hammer mills equipped with a blower for elevating the meal and food mixers which can be fed from ground-floor level, it is cheaper and better to arrange all needed food-preparing equipment on a single floor. Hammer mills which suck grain from a below-floor hopper are now available, but where hoppers are installed above the hammer mill or other machinery, they should be sited to take advantage of existing conveying equipment. In cases where a good food-preparing plant already exists in a building adjacent to a new drying and storage plant, it may be desirable to arrange for transfer of the grain from
storage to the grinding plant by means of a conveyor fed from the main system.

There are advantages from the viewpoint of dust control and insect infestation control in having the food-preparing plant and the grain store separated by at least a dust-proof partition. In the case of both the grain store and the food-preparing plant, however, control of dust is largely a matter of choosing suitable equipment and installing it so as to prevent the creation of dust, rather than of confining it to particular areas.

Control of Dust in Grain Stores

All grain stores are potentially dusty, and when heavy dust pollution is added to the fumes and moisture exhausted from a typical direct-fired drier, the result can be an atmosphere which is at best unpleasant, and at worst may seriously endanger the health of those who have to work for long hours in the building. Dust also provides harbourage for insects and mites. It is much better to take some care to avoid dust at the planning stage, rather than have to take expensive remedial action afterwards.

It is not usually practicable to solve a dust problem, in an efficient and economical way, simply by installing an extraction fan in the gable, though this can sometimes help if the fan is adequate in size and care is taken to ensure that fresh air enters the building at a suitable point or points so that there is a straightforward air flow right through the building. This method, however, has serious limitations, e.g., the power needed to achieve a sufficient air flow and the difficulty of ensuring that dust is not just picked up from one place and dropped in another. In general, this method is only suited to improving the atmosphere above the tops of silos, where the roof space itself provides an effective large-capacity duct above the silos. The only effective way of getting dust right out of the building is to confine it in ducts or pipes of fairly small cross-sectional area, so that the dust particles remain airborne until they reach the outside or are deposited in a settling chamber.

The main sources of dust in grain stores are:

Cleaners. Here the solution is so obvious that it is surprising that simple winnowers are still offered to farmers. The only logical choice of cleaner is an aspirating type which enables the dust and chaff to be ducted direct to a suitable collection point separated from the atmosphere of the building. Methods are discussed on p. 118.

Conveyors. Every time grain is moved, dust is created due to the rubbing of grains on one another. The amount of dust depends on the type of grain, its dryness, and its initial cleanliness, but most installations must be designed to cater for very dusty grain occasionally. Methods of control depend on the conveying method. Pneumatic conveyors are the worst offenders, but extreme dustiness is only one of the reasons why mechanical conveyors are now preferred. It is fairly simple to remove dust from any kind of conveyor where the mechanism moves in an enclosed trunking (e.g., a bucket elevator). The general principle is to suck the dust-laden air along a pipe or trunking, and deliver it out of the building.

The most difficult problem is removing the dust where the grain is de-
CHOICE OF DRYING SYSTEM

Driers. Some driers, notably horizontal reciprocating types and inclined cascade types, give rise to a very dusty atmosphere unless a canopy and extractor fan is installed. Fortunately, most drier manufacturers are now convinced of the need to avoid contaminating the atmosphere of the drier building with dust and fumes, and most are now able to supply a suitable canopy and fan, which can exhaust directly out of the building. Other manufacturers aim to solve the problem by a suction drying system, and this can certainly be effective in respect of dust control.

Electrical Wiring

The fact that electricity can be wired to almost any point about the farm buildings should not be allowed to obscure the need to keep heavy electrical installations well grouped together, and within easy reach of the supply point. A grain-handling plant will often need expensive heavy wiring, which may sometimes have to go underground from the supply point. If wiring considerations are not borne in mind from the commencement of planning, the total cost of the wiring on a comprehensive layout may be several hundred pounds.
Continuous Driers

PRINCIPLES AND DESIGN OF CONTINUOUS DRIERS

Continuous driers extract the moisture from the corn rapidly. All commercial models employ the principle of hot-air drying, and in order to keep the size of the machine and the power used by the fans within practical limits air is used at the highest temperature to which the particular type of grain can be safely exposed (a roughly constant amount of heat is necessary to achieve a given amount of drying, and the higher the temperature permissible, the less air is necessary to carry this heat to the grain). As the hot air passes through the grain it gives up heat which evaporates water but also raises the temperature of the grain. The temperature of the grain never reaches that of the air; the closeness of the maximum temperature reached by the grain to the air temperature depends on the design of the drier and other factors.

A continuous-flow farm grain drier usually has the following components:

1. a compartment or compartments for containing the grain during the drying and cooling treatments, with reserve storage space for damp grain to ensure that the drier is always kept full during operation;
2. a means of causing a steady flow of grain through the drier, with controlgear to regulate the rate of flow;
3. a source of heat: usually an oil-fired furnace or more precisely, an air heater;
4. a fan or fans for moving the heated air through the grain;
5. devices for controlling the air temperature;
6. a fan for moving unheated air through the grain to cool it after drying.

Design and construction of continuous driers is too complex to be undertaken on the farm (Figs. 8 and 9); these machines are factory built and delivered complete or nearly complete. The configuration adopted by different manufacturers for the combination of the components listed above varies considerably. In nearly all continuous farm driers the actual drying process is carried out in beds of grain of moderate thickness (from a few inches to a foot or two, according to type) through which the drying air moves at right angles to the direction of movement of the grain, at a rate of the order of 50 c.f.m. per sq. ft of surface of the grain mass. Layout of grain beds may be substantially vertical, substantially horizontal, or inclined.

In vertical or tower driers the grain may be contained between sheets of perforated metal, in columns which may be arranged, for instance, as two walls along the long side of a rectangle, or as a cylinder, enclosing a plenum chamber from which hot air reaches the grain. Some vertical driers have the grain wall enclosed between alternate slats against which the grain rests at its angle of repose; in another type the grain forms a continuous column into which air is introduced and exhausted by successive rows of ducts crossing the grain mass, the plenum chamber being on the outside of the grain column; airflow in this type of drier is mixed, partly crossflow, partly co-flow and partly counterflow. The flow of grain through vertical driers is maintained by gravity, the grain having been elevated to the reserve space incorporated...
CONTINUOUS DRIERS

Fig. 8. Continuous grain drier with cleaning and conveying equipment.
in the upper part of the drying chamber. Grain is released from the bottom of the columns by control devices of varying complexity—some driers have fluted rollers rotating with variable speed, or gates oscillated with variable frequency, and others a mechanical agitator to ensure a flow of grain through a simple slide used to regulate it.

Simple horizontal driers have a single bed of grain which is kept moving from the inlet to the outlet end of the drier. The plenum chamber is under the grain, and only one perforated or louvred floor is necessary. In one form of horizontal drier, the grain is moved by a conveyor. In another, the drier bed is slightly tilted, and oscillated to keep the grain moving.

Multiband driers consist essentially of horizontal drier conveyors mounted one above another so that the grain travels in alternate directions, falling from the end of one band to the beginning of the next. Control of output of horizontal or multiband driers, in which the grain is moved by conveyors, is achieved by varying the conveyor speed, and in oscillating driers by adjusting the dams which retain the grain.

Inclined bed driers, like horizontal driers, need only a single bed to support the grain but the grain moves down the drier by gravity and the output rate is governed by rate of removal from the foot of the incline, depth being maintained by a series of vaned cylinders. Horizontal conveyor driers, including one slightly inclined type, are adaptable to green crop drying, though the economics of the latter process are such that it is now extremely rare for a single drier to be used for both grass and grain.

Other types of continuous drier include counterflow driers, in which the grain flow is normally downwards, the air moving upwards through the grain. This arrangement has various advantages in theory, and is intrinsically economical in fuel, but as the depth of the grain bed is comparatively great, fan power is higher than in conventional driers. In fluidized bed driers the air passes through a horizontal bed of grain sufficiently fast to move the grain: very good mixing of grain and air is achieved, but again fan power is high. Good mixing is also achieved in rotary drum driers, but these are not normally used for grain-drying in Britain because of their high cost with the restricted temperatures used for drying grain.

Layout of fans and air heaters varies with design, but is basically of two kinds. In one, the main fan draws hot air from the furnace and blows it into the plenum chamber. After going through the grain, the drying air then usually passes from the drier directly into the surroundings. Unless the drier is situated in an open-sided shelter, this arrangement makes for unpleasant working conditions as the exhaust is warm, moist and dusty, and in addition usually contains sulphur fumes from the fuel. Most manufacturers of such driers supply, as standard or as an extra, a hood, usually with a supplementary fan, so that the exhaust can be ducted outside the building in which the drier is housed. Some more elaborate types of drier with this arrangement of fan and air heater, notably those in which the air enters and leaves the grain mass through cross ducts, have a built-in chamber to collect the exhaust air, from which it may be ducted outside the building.
Fig. 9. Some types of continuous drier
A Twin column vertical drier (grain downstream of fan)
B Horizontal drier with oscillating bed (grain downstream of fan)
C Multiband conveyor drier (grain upstream of fan)
D Inclined bed drier (grain downstream of fan)

KEY (numbers 1-6 correspond with those on p. 42).
1. Grain compartments
   (a) reservoir
   (b) drying compartment(s)
   (c) cooling compartment(s)
2. Means of causing and regulating grain flow
   (a) feed
   (b) overflow
   (c) regulating mechanism
3. Air heater
4a. Hot air fan(s)
4b. Hot air chambers
5. Devices for controlling (and indicating) hot air temperatures
6a. Cooling air fan
6b. Cooling air chambers
7. Grain discharge
A variant of this kind of furnace and fan arrangement is that in which the oil-fired air heater is situated downstream of an axial-flow fan, so that the fan motor is not overheated.

The other kind of layout is that in which the grain compartment is situated between the air heater and the main fan. Ducts can easily be connected to the delivery side of the fan so that the exhaust is taken outside the building; as static pressure in all parts of the drier is below atmospheric, this arrangement intrinsically provides a clean atmosphere surrounding the drier. The designer is faced with the problem of ensuring satisfactory mixing of the air-streams from various parts of the furnace, as the fan rotor is no longer able to mix them at source.

Cold air fans are sometimes arranged to blow the cool air through the grain and sometimes to draw it through. Where the drying air is drawn through the grain the cooling air is also usually drawn through the grain by the main fan. Where cooling air is blown through the grain, it is advisable to ensure that the fan is not drawing in the warm moist air just exhausted from the drying compartments; if necessary, ducting should be installed to bring cool air from outside the building, though careful siting of the drier near an opening may make this unnecessary.

**CHOICE AND INSTALLATION OF CONTINUOUS DRIERS**

In addition to the general considerations on choice of drying system discussed on pp. 27–36, choice of a continuous drier requires study of several factors which will greatly influence cost and layout of the plant.

**Drier Rating**

Continuous driers are usually rated on their output of grain dried at the hot air temperature recommended for milling wheat, when the moisture content is reduced by 4, 5, or 6 per cent from 21 per cent. It is important to note to which percentage reduction a rating refers, as obviously a drier rated at 6 per cent reduction has approximately \( \frac{5}{4} \) times the drying potential of one rated at the same output at 4 per cent reduction. The output actually obtained depends on the hot air temperatures used for the various types of grain dried; on the resistance to airflow of the particular grain dried; and, to a small extent, on atmospheric conditions. At one time outputs claimed for continuous driers were often decidedly optimistic, but current types appear to be more realistically rated. Official test reports give reliable ratings for certain driers.

**Matching Drier with Grain Acreage and Combine Capacity**

It is impossible to give a general rule to enable a correct choice of drier size to be made. At one extreme, many farmers succeed in combining all their grain without using a drier at all; in favourable seasons, driers may not need to be used even where they are available. At the other extreme, in wet districts, practically all the grain combined must be dried. Acreage of grain harvested per foot of combine cutter bar and acreage of grain per ton per hour nominal rating both vary enormously in practice; a survey in the south
and east Midlands showed that, in this comparatively dry area, 50–100 acres of corn were commonly catered for per ton per hour nominal drier rating, though many farms had much less drier capacity. The use of larger combines on a given cereal acreage does not necessarily imply a need for larger driers, as use of a larger combine on a fixed acreage should enable grain to be harvested at a generally lower moisture content. However, it is desirable that a continuous drier should be large enough to deal with the expected daily output of the combine in unfavourable weather conditions by working the drier for long hours if necessary; but without raising the air temperature above safe limits. Most farmers find it inconvenient to run driers for 24 hours a day, but 16 hours a day is often practicable. Using this criterion, a combine force expected to harvest 12 tons per hour under average conditions working for 8 hours a day, would be matched by a 6 ton per hour drier.

It is inadvisable to put in too small a drier, as, in a wet season, there will be a temptation to raise temperatures beyond safe limits in order to increase output.

Cost

There is a considerable range in capital cost between the most and the least expensive types of drier. Driers designed primarily for mill use are intended to work a far greater number of hours per year than farm driers, and their heavier construction and greater elaboration is reflected in higher cost. Farm driers, working at the most a few hundred hours per season, will last with reasonable care for many years, in spite of comparatively light construction. Size has an influence on the cost of driers, as some parts cost almost as much when scaled down as when made for larger driers. As a very approximate guide, driers of 3 tons per hour rating and above, cost about £500 per ton per hour rating (at 1964 prices); a 1 ton per hour drier, however, would cost around £800–1,000 for the drier alone.

Building Considerations

If a drier is to be installed in an existing building, the type chosen may have to depend largely on the space available in the building itself. Horizontal driers are particularly suitable for low buildings, and can be installed even under low beams with a clearance of a few inches. On the other hand, where plenty of head room is available, a vertical drier takes less floor space than other types. Multiband and inclined conveyor types are intermediate in their requirements for floor space and height. If a new building for drying and storage is to be erected, it will usually be more economic to make the drying bay of a height equal to or greater than that necessary for the storage bays, to accommodate a vertical drier or one of the intermediate types. However, the floor space required by modern types of horizontal drier is reduced as far as possible by the placing of fans and air heater under the drying compartment, and these driers may be suitable in new buildings in certain instances.

Crop Considerations

If large acreages of the same kind of grain are grown, or some mixing of varieties does not matter, for instance with feed barley, it is unimportant if
a little grain of two kinds is mixed in the drier when changing from field to field. At the other extreme, when corn is being dried for true-to-type seed, it is important to be able to clean out the drier thoroughly. Horizontal or inclined driers are then usually indicated, and those with louvred beds are easier to clean completely than those with perforated beds. On most types of drier, if crops are to be kept separate, it is necessary, when concluding the drying of one lot, to feed into the drier some similar grain that has already been dried, to prevent the hot air from escaping past the damp grain. The ratio of drier holding capacity to rated output should therefore be taken into consideration, if many such changes of variety have to be made, as some driers hold more grain than others for the same output rating.

**Fuel**

Modern continuous farm grain driers are normally supplied with direct air heaters fired by gas oil, a similar oil to that used in diesel engined tractors. Electricity is impractical for the heavy loadings which are required for continuous driers, while the saving in using solid fuel is offset by the convenience of modern oil furnaces. Large installations, for instance at mills or cooperatives, may have indirect air heaters, in which a cheaper fuel (heavier oil or coke or coal) is burnt, and the heat from the furnace gases passed to the drying air either by a gas-to-air heat exchanger, or by a boiler and steam-to-air heat exchanger.

**Power**

The use of a number of separate electric motors to power each of the various components of a continuous drier has become almost universal, though some makes can be supplied, if required, with a countershaft for engine drive where electric power is not available.

**Layout**

Good layout of a drying and storage plant, is fundamental to successful and economic operation. The arrangements for reception of grain are of particular importance. As the hourly working rate of the combine will normally be in excess of that of the drier, it is desirable to include in the installation a holding bin in addition to the grain intake pit. As in most grain-drying installations, a pre-cleaner is desirable, and this should preferably be installed between the pit and the holding bin or bins, to remove trash from the damp grain. Elevators will be required to raise the grain from the intake pit to the holding bin, from the holding bin to the drier intake, and from the drier output to the conveyor taking it to store. Some driers incorporate one or more of these elevators, but it is more usual for the drier to be supplied without elevators: in preliminary planning this should be taken into account. The elevators already mentioned will usually be adapted to lift grain to the grain cleaner or dresser, which is sometimes incorporated in the layout, to ensure the production of a good commercial sample. Finally, if grain is sold off the farm, either a high bulk loading bin, with a capacity equal to that of a large
bulk grain lorry (say 20 tons) should be provided, fed by a normal elevator, or a high capacity conveyor and elevator system should be installed.

Provision should be made in the conveying system for moving grain from one bin to another, and for moving grain from a storage bin back to the drier: it may be necessary in some circumstances to partly dry grain, to a moisture content safe for temporary storage, and subsequently to complete the drying.

To make storage completely safe, it is desirable to include in the layout provision for cooling of the grain in store to a temperature below 60°F. Grain, as it leaves a continuous drier, may in fact be considerably above this temperature, as, often at harvest, the atmospheric air is at a higher temperature and the best of cooling on the drier cannot quite reduce the grain to ambient temperatures. Arrangements for cooling in store can be much simpler than for drying on the floor or in silos, with widely spaced ducts and a comparatively small fan, which is run at night or during other periods of low ambient temperature.

**OPERATION OF CONTINUOUS DRIERS**

**Before Work**

*The manufacturer’s instruction book should be carefully studied before the drier is used. The following general suggestions cannot replace the detailed information usually given for each type of drier.*

Before the beginning of each season remove any dust or rubbish which might foul the grain-drier perforations, or working parts, and clean the inside of the drier and ducting thoroughly. Run the plant for a short time and look for air leaks in ducting, slack drives, loose nuts, or any similar faults. Make sure that fans and conveyors are running in the right direction (centrifugal fans still deliver some air the right way, but at greatly reduced efficiency if they are reversed, for instance by accidental reversal of motor connections). It is particularly important to clean out any dust which collects in hot air ducts and the hot air chamber, as this dust becomes very dry and constitutes a fire risk. Horizontal and inclined driers are fitted with removable plates so that the hot-air chamber can be cleaned out easily, and this should be done daily during the season.

*Adjusting Discharge Rate*

It is advisable to run the drier to obtain a rough idea of output rate with various settings of the discharge control. Some vertical driers with twin walls have separate discharge gears for each column, and these should be set to give equal rates of discharge. Discharge rate usually varies according to the type of grain, and with the same type of grain according to moisture content, so it will not be possible to obtain precise settings.

*The Furnace*

The working of oil-fired furnaces should be checked before any grain is dried, so that a clean smokeless flame is obtained. Incomplete combustion due to an excess of primary air is indicated by blue smoke, and due to an excess of oil by black smoke. Either is liable to spoil the grain, and appropriate adjustments should be made, calling in a specialist if necessary. If adjustment is
provided of the quantity of diluting air, it is normally advisable to use the maximum quantity possible. If the burner capacity is sufficient to heat this to the required temperature, reduction of air flow will reduce the rating of the drier; if the burner capacity is not sufficient, little if any gain in output will be obtained by shutting down the air to achieve the desired temperature as long as the burner is fully on. Solid-fuel fires should be lit well in advance of the start of drying each day: while the fire is smoking, all furnace gases must be directed to the atmosphere and drying should not be started until a clean bright fire is obtained.

**During Work**

When starting for the first time in the season, or after the drier has been emptied to change from one crop to another, the grain that is in the drying and cooling compartments of a continuous drier when drying is begun will not be properly dried, and should be returned to the intake. Most continuous driers are provided with an overflow chute from the feed hopper, which returns grain to the pit. To ensure that the drying compartments are full and thus prevent an escape of hot air, the feed elevator should be set so that there is always a trickle of grain down the overflow.

**Control Methods**

The method of control normally recommended is to set the hot-air temperature to the maximum permissible for the type of grain being dried (p. 50), and regulate the output rate so that the desired final moisture content is obtained. When the grain requires a reduction of more than 6-7 per cent in moisture content, it is usually advisable to dry to about 18 per cent moisture content and put the grain through the drier again at the earliest possible opportunity.

Another method of control, sometimes used when the drier rating is comparatively large in relation to that of the combine, is to run the drier during the day at a constant output rate to keep pace with the combine. Hot air temperature is varied, subject to not exceeding the maximum permissible. If the grain is insufficiently dried with the maximum permissible temperature, it is put through the drier again overnight.

**Temperature Control**

With either method of drier control, it is necessary to ensure that the control of hot-air temperature is accurate and effective. Oil fired driers are usually fitted with a thermostat operating a high-flow flame control, or with a proportioning burner in conjunction with an over-temperature cut-out and automatic re-ignition. With the latter arrangement it is desirable for the operator to set the burner from time to time during the day, as atmospheric temperature varies, so that cut-out and re-ignition are not constantly occurring. With either type of burner, the setting should be checked against the drier thermometer, which should in turn be checked by inserting a reliable mercury thermometer into the air flow.

**Recommended Hot Air Temperatures**

The maximum permissible hot-air temperature depends on the use to which
the grain is to be put, its moisture content, and drier design factors. In the absence of definite instructions for the use of other temperatures, those shown in Table 8 (which have been agreed by authorities representing the purchasers of the various kinds of grain) should be observed.

<table>
<thead>
<tr>
<th>Grain and purpose</th>
<th>Max. air temp. °F.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain for stock feed</td>
<td>180-220*</td>
</tr>
<tr>
<td>Wheat for milling</td>
<td>150</td>
</tr>
<tr>
<td>Malting barley and seed corn up to 24 per cent m.c.</td>
<td>120</td>
</tr>
<tr>
<td>Malting barley and seed corn above 24 per cent m.c.</td>
<td>110</td>
</tr>
<tr>
<td>Oily seeds</td>
<td>115</td>
</tr>
</tbody>
</table>

(The safe air temperatures for drying vegetable seeds are lower than these in most cases)

* Feeding properties are not harmed by temperatures up to 220°F during drying; but the higher the temperature used, the more difficult it is to cool the grain effectively before storage.

It should be noted that the maximum temperature recommended for drying wheat for milling is considerably less than that for stock feed: use of temperatures over 150°F may result in modification of the gluten with consequent damage to the baking quality of the flour.

**Output Rate, Moisture Removal and Temperature**

With a given hot air temperature, the weight of water removed per hour by the drier, and therefore the output rate x reduction of moisture content percentage, is very roughly constant. Thus, if at 3 tons per hour output rate, grain is dried from 21-17 per cent moisture content, at 2 tons per hour it will be dried from 21-15 per cent. This is not strictly true, for various reasons, but can serve as a guide for making trial adjustments. The evaporative efficiency of most kinds of drier increases when the output rate is increased: Fig. 10 shows an example of the performance of a drier on test, in which it will be noted that the output rate when drying from 21-18 per cent is more than twice that when drying from 21-15 per cent. Evaporative efficiency tends to be high when the moisture content of the grain entering and leaving the drier is high, but against this the amount of water to be removed for a given nominal reduction in moisture content is more at higher moisture contents. The idea of reduction in percentage moisture content is useful for approximate calculations, but like most sums with percentages is apt to be misleading. The weight of moisture removed when X tons of wet grain is dried from 21-15 per cent moisture content is

\[ \frac{6}{100-15} \times X, \quad \text{i.e.} \quad \frac{6}{85} \times \text{not} \quad \frac{6}{100} \times X. \]

Table A5 (Appendix) shows the reduction in weight that takes place when grain is dried from various moisture levels.

The effect of change in hot-air temperature is that output will be very
approximately proportional to the difference between the hot air temperature and atmospheric temperature. The effects of atmospheric temperature and humidity become more marked the lower the drying temperature, so prediction of the performance of a drier becomes more and more uncertain the lower the hot air temperature. As a guide, a drier capable of an output of

![Graph of drier performance](image)

Fig. 10. Graph of drier performance

3 tons per hour drying from 21–15 per cent with a hot air temperature of 150°F will have an output of 4 tons per hour at 180°F, 5 tons per hour at 210°F, and only 1½–2 tons per hour at 120°F, depending on atmospheric conditions.

Drier output is influenced by the resistance of the grain to air flow, and a setting satisfactory for one type of grain will not necessarily be satisfactory for another at the same input moisture content. Different types of grain vary considerably in drying rate when dried in thin layers, but the variation from this is reduced by the thickness of the bed in most practical farm driers.

**Setting the Drier**

The drier may be approximately set after determining the moisture content of the grain delivered to it, bearing in mind that many types of moisture meter will give only an approximate indication of the moisture content of newly harvested grain (see p. 125). After this, the setting becomes a matter of trial and error. Moisture content readings should be taken of the dried grain as often as practicable, and not less than about every half-hour (unless conditions are so stable that little change is taking place). Experience will show
how much output rate should be reduced if the moisture content tends to rise. Occasional readings of the moisture content of the incoming grain will enable the experienced operator to anticipate changes and keep output moisture content reasonably constant. Changes to the output rate should be gradual unless input moisture readings indicate a sudden change. A rough calculation can be made of the time in hours necessary for any change to be fully effective, by dividing the holding capacity of the drier in tons by the new output rate in tons per hour.

Automatic controllers for continuous driers use the principles just described to control output rate electronically. If a drier is fitted with an automatic controller, the output moisture content should be checked with an ordinary moisture meter several times at the commencement of drying each type of grain, so that the controller can be set correctly. Afterwards, the controller should hold the output moisture content reasonably constant, though an occasional check is advisable so that any tendency to 'drift' can be compensated.

Breakdowns

If, for any reason, it is necessary to stop the plant when it is full of grain, the input elevator feed should be stopped. If the stop is longer in duration than a few minutes, the burner should be turned down or turned off altogether. In the unlikely event of fire in the drier, stop all fans and empty the drier as quickly as possible: common sense will dictate in the particular circumstances whether the grain should be damped while still in the drier or as it leaves it.

AFTER WORK

At the end of the season and again before the new season, the drier should be cleaned out thoroughly. Grain should be removed, since not only may it provide food for insects, mites and rodents, but it may sprout and will tend to cause rapid rusting of the parts with which it is in contact. Appropriate parts of the drier should be painted, as there is a great tendency to rust because of the action of furnace gases and the long periods of idleness between seasons.
Batch Driers

Batch driers are considered here as driers which hold, or support, and dry a relatively small batch of grain in sacks or in bulk, the grain normally remaining static during the drying process. In-sack driers and tray driers are the commonest form of batch driers, but hoppered chamber driers, with inlet and exhaust ducts distributing air through the grain mass, also fall into this category. In addition, radially ventilated silos and ducted silos (in which the drying air travels only a short distance, 3 ft or less, through the grain), even when their capacity is quite large (over 20 tons), may be used as batch driers, due to their ability to dry relatively quickly when appropriate combinations of airflow and heat are applied. These types of drier are considered in detail on pp. 71-3.

Batch driers, though inevitably introducing discontinuity into a grain drying and storage operation, can be an attractive proposition where capital cost must be kept to a minimum. Many farms already have buildings suitable for sack storage, and if the quantity of grain handled is not large (say 30–100 tons) the low capital and operational cost of an in-sack drier makes a strong appeal. However, the trend is now firmly towards bulk handling at all stages after harvesting, and the sack drier does not fit in with this method. A simple bulk batch drier, such as a tray drier, is the next and obvious alternative to the sack drier. Capital cost need be little higher, as far as the drier is concerned, but modifications to buildings to make them suitable for bulk storage may also be necessary and expensive. Harvesting and drying in bulk, and subsequently handling in sacks, cannot be recommended except as a temporary measure.

In-Sack Drying

Grain and other seeds harvested in thin hessian sacks by combine harvesters can be safely dried in batches in the sacks, using a simple platform drier in which slightly heated air is forced through the grain in the bags on the platform as shown in Fig. 11. Capital cost is low but, although the labour involved in loading and unloading the platform is not excessive, particularly if the layout is well planned, it often demands unwanted breaks in the sequence of harvesting and storing operations. However the plant can be left unattended throughout the calculated drying cycle time.
Drying Rate

Drying rate varies according to the rate of airflow through the bags and the amount of heat applied. For example, a typical oil-fired unit has a fan which delivers 5,700 c.f.m. heated to 25°F above atmospheric temperature, and uses 1 gallon of fuel oil an hour. This unit could deal with 2, 3 or even 4 or 5 tons of grain at a time according to the platform size. With a 2 ton loading such a plant would remove moisture at approximately 1 per cent an hour. Rather more than half this rate would normally be achieved by the same unit on a 4 ton platform. (Moisture extraction is slightly more efficient at lower rates of air-flow under normal atmospheric conditions, when unheated air has an appreciable drying capacity).

Using electrical heating, a 45 kW bank will remove moisture at approximately 1 per cent per hour from a 2 ton batch.

It is clear, therefore, that many combinations of airflow and available heat are possible to suit individual requirements. The farmer who wishes to dry large batches at infrequent intervals to reduce management problems, may choose a large platform, with a relatively low airspeed and temperature rise, whereas another farmer may require to dry small batches quickly, using a limited number of sack holes and the maximum recommended airflow and temperature rise. With a large-capacity drier, there is often considerable advantage to be gained by partitioning the air chamber so that only a part of the drier may be used when necessary.

Components of an In-sack Drier

The drier consists essentially of a heater unit, a fan and an air chamber, the roof of the latter forming the sack platform where drying takes place. Oil-fired units require, in addition, an oil storage tank.

Heater Unit

A number of satisfactory oil-fired heater units are available, and a typical one consists of an oil burner with a combustion chamber mounted in a light steel casing with a steel mesh inlet guard. The casing outlet is connected to the inlet side of a ventilating fan which draws air past the hot combustion chamber and delivers it, mixed with the products of combustion, to the air chamber, and thence through the grain in sacks. Drive to the fan is either by electric motor or stationary engine. The unit is designed to run automatically and unattended between batches, except for routine lubrication and fuel replenishment. Protection against power and flame failure is provided. Farmers who intend making up their own units should ensure that these necessary safeguards are incorporated.

In the case of all-electric units, a heater bank is fitted either to the inlet or outlet side of the fan. It is an advantage to arrange for the heater to be wired in stages; this allows a lower temperature rise to be selected when a batch is to be left on all night to dry slowly. Although guards must be fitted at the fan inlet, very small mesh should be avoided as this reduces the effective inlet size very considerably.

As with continuous and tray-type driers, solid fuel furnaces burning coke can be used. These are cheaper in capital cost than oil-fired heater units and are economical to run. However, they need more labour and skill in opera-
tion, and are seldom chosen now that reasonably priced units of the oil-fired type are available.

On some farm-built tractor- or engine-driven platform driers, the air is warmed on its way to the fan by being drawn through a partially enclosed housing which surrounds the power unit. But the low horsepower requirement of the low-pressure fan generally means that the small engine, or the lightly loaded tractor, does not produce sufficient heat to give a good drying rate, and the addition of a supplemental source of heat is normally required for batch drying.

**Fans**

Centrifugal fans are rather less efficient and less compact than axial-flow fans, but are more adaptable to variation of grain depth and quieter. Axial-flow fans are ideally suited to the steady resistance to airflow obtaining in the sack drier, and their power requirement is low for a given duty; the built-in motor gives a compact unit which offers considerable advantages in some situations. To achieve a drying rate of 1 per cent an hour, an airflow of the order of 130 c.f.m. in per sack hole with a 25°F temperature rise is required.

**Drier Platform**

One type of platform construction is illustrated in Fig. 12. This shows part of a prefabricated platform with the aperture slabs at ground level mounted on support blocks where four aperture slabs meet. Access into the air chamber is essential for cleaning purposes. Fig. 13 shows part of a continuous platform made up of welded mesh reinforcing fabric supported on timbers, again with the platform at floor level to facilitate movement of sacks on and off the platform. Floor space is much more effectively used with this continuous type of platform, but air leakage between the sacks is likely to be greater than where individual sack apertures are used, and movement of a sack barrow over the platform is also impossible without laying down a special track consisting of planks or sheet metal. The continuous platform is likely to be of particular interest to farmers drying hay artificially in walled bays. If the fan used for hay-drying is suitable, 2–4 layers of sacks may be dried on the floor normally used for hay-drying.
Two thermometers, one in the warm-air duct and the other in a position to give the shade temperature at the fan inlet, are required. In addition, an instrument for measuring grain moisture content is very desirable and can effect considerable fuel economies by reducing overdrying to a minimum.

Completion of drying is not easily determined by a moisture test, owing to lack of uniformity. A method of calibrating the drier involving weighing before and after drying is described later.

Installation Hints

The plant should be arranged so that there is easy access to the drier platform for unloading damp grain and for taking off dried grain. Consideration should also be given to the possible need to transfer the grain to a store, either in sacks or by mechanical or pneumatic conveyor; careful planning will save labour in the handling of bags on and off the drier platform. The following are among the important points to consider when planning an installation:

- it is often advantageous to sink the platform ducts below floor level, so that the top of the platform is at the floor level of the rest of the barn;
- where the natural lie of the land permits it is advantageous to have access to the building at both platform level and from a low-level roadway. A platform top, flush with the general floor level and combined with access at two levels, is an ideal arrangement;
- there should always be a good area of floor space at the same level as the drier platform, so that temporary storage can be provided both before and after drying. With some 'square' layouts, it may be worth while to introduce a central passage to permit the easy use of a sack barrow; but the use of a sack barrow having an extended axle so that the wheels can run on either side of each grid opening makes this less important;
- wherever possible, apertures should be set at right angles to the main runway to facilitate loading and unloading by a sack barrow which spans the apertures;
the problem of dressing and sacking-off for sale after drying should be borne in mind from the start, since it is often advisable to allow for an elevator hopper to be located at a point near the drier platform. Dressing before drying in sacks is not recommended; it not only adds to organizational problems but is not nearly so effective as dressing after drying;

it is highly desirable to house the heater unit separately, either in an enclosed structure within the building or, better still, in a shed outside the main building. In fact, isolation of the heater unit is insisted upon by some insurance companies. Some of the practical advantages gained by separate housing are: the heater unit can be kept clean, thus ensuring good performance and materially reducing the risk of fire due to the presence of combustible material; there is less likelihood of moist air emerging from the drier being recirculated;

adequate ventilation in the upper part of the building must be provided to allow damp air to escape.

OPERATION

SACKS: CHOICE AND FILLING

Light hessian combine sacks should always be used. Thick railway and similar sacks are not suitable; the thicker material offers considerable resistance to airflow and seriously reduces the drying rate. Furthermore, a larger size sack is heavy to handle and unsuitable for the standard platform aperture.

Sacks should not be filled to capacity otherwise a good air seal is difficult to achieve and, in addition, the required uniform depth of grain layer is impossible to attain. A uniform grain depth of 7-8 in. should be the aim. For wheat, oats and barley, the best guide is to fill the combine sacks with about 24 in. vertical depth of grain and tie about 2½ in. from the mouth.

The alternative method of filling sacks to maximum capacity on the combine and then adjusting the quantity at the drier introduces an extra operation, which not only requires more labour, but may seriously interrupt the smooth running of the whole operation.

SACK COLLECTION

When collecting sacks from the field it is best to follow the route taken by the combine. Grain harvested in the morning and evening is likely to have a higher moisture content than that which is cut between times. Collection of sacks across the combine route is likely to result in quite wide variations in moisture content in a single load. On the drying platform, wide variations in moisture content between individual sacks results in uneven drying and makes the estimation of the drying period unreliable.

Some farmers find it advantageous to use red string to tie sacks in the early morning and later evening, when it is known that the grain is unusually damp. However, unless exceptionally bad harvest weather forces the farmer to go ahead with combining, starting should be delayed as long as possible in the morning. It is much cheaper to let the corn dry naturally in the ear; and the hour or so delay in starting can mean a drop in moisture content of 2 or 3 per cent if the weather is favourable.

GRAIN CLEANING

It is neither necessary nor desirable to clean grain before drying on a sack drier. It has been found that up to 2 per cent rubbish, which is more than
should be expected in a normal season, does not significantly interfere with the flow of air through the sacks. Furthermore, greenstuff, weed seeds and other contaminations are very much more easily removed after drying.

**DRYER CONTROL**

For all practical purposes a 25°F rise in temperature above atmospheric, or 100°F drying temperature, whichever is lower, is as much as is normally required for cereals. Temperature lifts greater than 25°F can result in considerable overdrying of the layers nearest to the aperture. Many sack driers are designed to dry at lower temperature rises, and this applies particularly to electrically heated types; drying is naturally slower at lower temperatures but there is some economy in heating costs.

**CALIBRATION**

The drying rate of a particular sack drier is best found by trial during operation. Although a grain moisture meter may be used to check grain before and after drying (when the grain is cooled and mixed), initial calibration of the drying rate of an in-sack is perhaps best carried out by a weighing method. Several sacks from different parts of the platform should be weighed as accurately as possible and the individual sack weights recorded. If, after a period of 2–3 hours the sacks are reweighed, the loss in moisture in lb can be determined reasonably accurately. For example, if one sack before drying weighs 112 lb and 106 lb after drying for 3 hours, moisture removal is \( \frac{112 - 106}{112} \times 100 = 5.5 \) per cent per hour. The mean rate of removal for several sacks should be taken as the drying rate for the particular cereal, and the calibration repeated for the different seeds to be dried and for a range of temperature lifts, if it is intended to vary the latter.

Having calibrated a particular sack drier in this manner, the farmer will know fairly precisely what time is needed to dry a particular batch and be able to avoid either under- or over-drying. If he has accurately measured the initial moisture content, it is unnecessary to attempt the almost impossible task of accurately measuring the moisture content immediately after drying.

**COOLING**

Provided the grain is dried down to about 16 per cent and stored in hessian sacks clear of the floor and with adequate air space between rows, grain need not be cooled before coming off the drier. In practice, however, it is usually necessary to stop the fan during unloading, and it is best to turn off the heater a few minutes earlier. If bulk storage follows immediately after drying, cooling down as near 60°F as possible is advisable. This can be effected by cutting out the source of heat 15–30 minutes before removal of sacks from the platform.

**IN-SACK DRIERS TO SUPPLEMENT THE PRINCIPLE DRIER**

Many predominantly cereal growing farmers also grow appreciable quantities of grass and other small seeds and on such farms, unless the drier is
capable of dealing with small seeds, the provision of a sack drier platform can conveniently solve this problem. In many cases, particularly with bulk driers (ventilated bins, floor driers, etc.) it is practicable to bleed off a proportion of the air from the fan of the principle drier directly to the sack platform.

**BATCH DRIERS FOR GRAIN IN BULK**

Horizontal tray driers were the first type of bulk batch grain driers to be developed. A possible attraction of this design, for farms where small quantities of both grain and grass require drying, is that the drier can be arranged to do both jobs.

More complex batch driers are now available in which the drying chamber or tray can be emptied and refilled with grain for drying with so little delay that they compare favourably with continuous driers, unless a prolonged cooling period is necessary before the dried grain is stored in bulk.

Horizontal tray driers range in capacity from 1 to over 5 tons. Most of those sold as complete units may be tipped either by hand screw or hydraulically. The floor of a typical tray drier is made of stiffened perforated plate or wedge wire, and sealing of the air chamber beneath is automatically effected when the tray is returned to the drying position. Heat in the smaller capacity models may be provided by electricity or oil, but oil is generally preferred in the large sizes.

Construction of a tray drier on the farm is not unduly difficult and is likely to give satisfactory results if a suitable combination of airflow and heat is provided.

Fig. 14 shows the general layout of a tray drier supported on a brick structure which forms the side walls of the air chamber beneath the drying tray. An inclined tray gives easy filling and emptying, and practical tests indicate that an angle of inclination of about 17° to 20° is satisfactory. For ease of operation it is an advantage to provide a self-emptying damp grain hopper of equal capacity to the tray. The hopper should be located above the higher end of the tray and should empty across the whole width of the tray. In addition, a reception pit for the dried grain should be provided. A single elevator can be arranged to serve both damp grain hopper and dry grain pit. A further useful addition is a separate wet grain pit, as shown in Fig. 14, large enough for at least one trailer load of grain, so that when the plant is in full operation there is a minimum of hold-ups between batches.

A similar sequence of loading and unloading operations is achieved by the hoppered batch drier shown in Fig. 15. In this case, grain is dried in a special self-emptying chamber fitted with alternate layers of air inlet and exhaust ducts.

Fig. 7 gives an indication of the resistance of grain at different depths in a tray drier at various air speeds. For example, if the proposed tray has a floor area of 100 sq. ft, and an air speed of 50 c.f.m. per sq. ft through barley is decided upon, resistance attributable to the grain (at 2 ft depth) will be 2.8 in. w.g. To this must be added floor and duct losses which are likely to amount to 7/16 to 1 inch. w.g. depending on the layout. A fan capable of delivering 5,000 c.f.m. at 3·3 to 3·8 in. w.g. would therefore be required.

Table 9 gives the results of some experimental work at the National Institute of Agricultural Engineering to determine the drying time (for wheat)
in a tray drier at different rates of air flow and at different air temperatures. The grain depth in all cases was 2 ft, and the drying was from 20 per cent to a mean of 14 per cent moisture content.

**TABLE 9**

*Drying times for wheat in a tray drier at 2 ft depth*

<table>
<thead>
<tr>
<th>Air flow (c.f.m./sq. ft)</th>
<th>Drying time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>at 100°F</td>
</tr>
<tr>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>40</td>
<td>8½</td>
</tr>
<tr>
<td>50</td>
<td>6½</td>
</tr>
<tr>
<td>60</td>
<td>5½</td>
</tr>
</tbody>
</table>
Another type of batch drier consists of a self-emptying hopper mounted above a self-emptying drying chamber of the same capacity. The drying chamber contains a system of hot-air inlet and exhaust ducts. When drying is completed, the grain is released to a hopper below, and the drying chamber is refilled from the wet grain hopper with the minimum of delay. The fact that the wet grain hopper may be filled while the drying chamber is in operation can result in almost continuous drying, and overcomes one inherent disadvantage of a single-unit tray drier. Separate wet- and dry-grain hoppers increase the flexibility of this type of unit.

At grain depths approaching 24 in. and over, and where moderately high temperatures are used, batch driers tend to result in uneven drying; but provided mixing before storage is reasonably thorough, this is not a serious disadvantage. The thicker the grain layer and the higher the temperatures employed, the greater the resulting moisture gradients. It is therefore essential, if the grain is to be put into unventilated bulk storage, to arrange for cooling and a conveying method which ensures thorough mixing.

If grain is stored in the same building as the drier, effective means of removal of hot moist air to the exterior should be provided.

The introduction of cheap and efficient auger grain conveyors has made the filling and emptying of batch driers much more satisfactory; and if a receiving pit and discharge hopper are provided little time need be wasted between batches.

Fig. 15. Batch drier with hoppers for both wet and dry grain
Drying Grain in Bulk

This chapter deals with systems of drying in which the grain is not normally moved from the drying compartment or area immediately after drying is finished, and may, if desired, be stored in the drier until required. The main drying methods included under this heading are (a) drying in bins or silos with perforated floors and vertical air flow; (b) drying ‘on the floor’; (c) drying in silos with perforated walls and radial air flow; (d) drying in silos with inlet and exhaust ducts. There is no sharp dividing line between drying in bulk and drying in batch, and the equipment for systems (c) and (d) can be used for either purpose. The only difference between drying in bulk and drying in a large batch is that batch drying can be carried out at a higher temperature, and the grain must be moved and mixed immediately after drying, in order to secure a uniform final moisture content.

The principles of drying have already been explained, but it is worth while to re-state here the main practical points which must always be borne in mind in planning or operating a bulk drying installation.

Drying in bulk is essentially a slow process. It depends on the use of air which normally has little drying capacity, and which is blown through the grain for such a length of time that the relative humidity of the air and the moisture content of the grain are finally in equilibrium. When drying is finished, there is little difference in grain moisture content between the point where air enters and that where it leaves the grain. So long as the air blown through the grain has a relative humidity lower than that corresponding to the grain moisture content indicated for equilibrium conditions by Fig. 5, it will tend to absorb moisture from the grain. Relative humidity is therefore a useful indicator of the drying capacity of the air, in relation to grain at a given level of moisture content. Drying capacity is, however, also a function of temperature, and this is a point which is sometimes overlooked. Thus, the drying capacity of air at 70°F and a relative humidity of 60 per cent in relation to grain which needs to be dried from 20 per cent is about 40 per cent higher than that of air at 50°F with the same relative humidity. Atmospheric temperature therefore influences the drying capacity of storage drying systems in two distinct ways, viz.,

- a high atmospheric temperature leads to higher drying capacity because drying capacity at a given relative humidity increases with temperature;
- because the total quantity of moisture contained in the atmosphere at any one time of year tends to be a fairly constant quantity, increase of temperature also tends to reduce relative humidity.

Conversely, at low atmospheric temperature, drying capacity is reduced in these two ways, and it is in conditions of low temperature, late in the year, that storage drying systems are most likely to encounter operating difficulties. This problem is discussed in some detail later.

In practice, as shown by the illustrations on p. 5 (Fig. 1C), in August average relative humidity is about 80 per cent in many important corn-growing areas, and a little higher in some; and even in the most favoured areas in August, there are 200-250 hours with a relative humidity of over 90.
per cent. This means that it would be practicable to dry grain to a satisfactory level (e.g., 16 per cent m.c.) in a storage drying installation, using only atmospheric air, if all of the drying could be completed in an average August; but this does not form a satisfactory basis for the planning of installations, and in practice it is advisable to provide for a temperature rise of up to about 6°F for the most favoured situations, and a little over 10°F for the most adverse conditions in which storage drying systems are used.

Relative humidity of the drying air can be reduced by other means than heating it, e.g., by the use of a chemical such as silica gel or by refrigeration, but in practice all methods other than warming the air are more expensive in capital cost, and do not provide any advantages sufficient to offset this.

**GENERAL CHARACTERISTICS OF STORAGE DRYING**

The process of storage drying may be illustrated by reference to drying in a simple ventilated bin with a perforated floor. Other storage drying systems differ in details, but not in essentials.

The grain is first dried at the bottom of the silo, where the air enters, and the drying zone moves progressively upwards. Fig. 16 illustrates the situation when drying is about half finished. The grain in the bottom of the bin is fully dried; drying is taking place just above the dry grain; and the grain at the top is still approximately at the same moisture content as it was when it was put into the bin. The drying zone is often narrower than indicated by the diagram, and when an appreciable amount of moisture has to be removed (e.g., from 20 per cent m.c.) the point which drying has reached may be easily checked by pushing in a metal rod or a sampling spear. Resistance of the damp-grain layer to entry of the rod is often much higher than that of the dry-grain layer.

The limit to effective application of storage drying systems is reached when the grain at the point where the air leaves takes too long to dry, and begins to deteriorate before it is dried. This grain, in these limiting conditions, will have been put into the silo at a high moisture content, and will have been ventilated only by air of high relative humidity, which can do no drying.
This limit is a factor of depth of the grain layer, air speed and air tempera-
ture. In practice, the power required to force air through grain increases
excessively for storage drying at air speeds of over about 35 c.f.m. per sq. ft,
and at the drying rate normally attainable with the more economic air
speed of 20-30 c.f.m. per sq. ft, the maximum recommended depth of layer,
when appreciable drying is required, is about 10 ft. The limit, as regards
initial grain moisture content for storage drying, is reached when a large
proportion of the grain has a moisture content of 21 per cent or more. Beyond
these limits, grain can be satisfactorily dried in storage driers in circumstances
where atmospheric temperature and relative humidity conditions are favour-
able, but planning of installations on such a basis cannot be recommended.

Since the air which leaves a storage drier is normally carrying an amount
of moisture corresponding approximately to the moisture content of the damp
grain layer, it is essential to make provision for removal of the exhaust air
from the building in such a way that re-circulation is avoided.

Experimental work has provided information which makes it possible to
predict the performance of storage drying installations in specified conditions.
For example, if driers are operated in the manner recommended later, it has
been found that, on average, about 12,000 cu. ft of warm air is needed to
remove 1 lb of water. On this basis, it requires an air flow of about 21 c.f.m.
per sq. ft of floor area to remove \( \frac{1}{2} \) per cent m.c. every 24 hours from grain
at 10 ft depth. It is not usually economic to provide such an air flow for the
whole drying area. In normal circumstances, it is satisfactory if about 25
c.f.m. per sq. ft is available over about one third of the drying area, provided
that an air flow of about 15 c.f.m. per sq. ft is obtainable over two-thirds of
the drying area, and not less than about 10 c.f.m. per sq. ft can be achieved
when all silos are ventilated. If a suitable fan and motor are chosen, it is
quite practicable to obtain air flows of this order. It should be emphasized
that these recommended air flows are related to the grain depths, initial
moisture content and atmospheric conditions already specified (10 ft, up to
21 per cent and normal harvest weather). Suitable operating methods for
adverse conditions are discussed later.

For drying grain on the floor it is recommended that the depth of undried
grain of a high moisture content (21 per cent or more) loaded at any one
time should not exceed 6-8 ft. This makes it practicable to manage with a
lower air flow than that already considered for 10 ft depth. As with ventilated
bins, however, storage drying on the floor is not recommended for areas or
methods of management where a high proportion of the grain is normally
harvested at over 21 per cent m.c.

In a radial air flow drier, the air is normally introduced through a per-
forated cylinder which stands in the centre of the cylindrical silo. The air
flows outwards and is exhausted through the perforated walls of the silo. By
choice of a suitable small or moderate silo diameter, the path of air through
the grain can be suitably limited (e.g., to 3 ft in a 7 ft 6 in. diameter silo, or
5 \( \frac{3}{4} \) ft in a 13 ft diameter one), and a fairly high rate of air flow per ton of
grain can be achieved. Exactly similar considerations apply to storage drying
in silos fitted with inlet and exhaust ducts. Here the distance between ducts
normally ranges from about 3-5 ft.

Table 10 gives examples of the relationship between grain depths, air
flows, grain capacities and drying rates for typical storage drying installations.
where the total storage capacity is about 250 tons and the amount being dried at any one time ranges from 40 to 180 tons. The figures given for the different types are not exactly comparable, but give a general indication of the main characteristics of the three types of installation. Ducted air flow silos are not included, since these are usually made self-emptying and are used as batch driers.

**Table 10**

*Comparative characteristics of three storage drying installations*

<table>
<thead>
<tr>
<th>Storage Method</th>
<th>Drying Method</th>
<th>Vertical-air-flow</th>
<th>On-floor</th>
<th>Radial-air-flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage dimensions</td>
<td></td>
<td>8 rectangular bins, all ventilated, each 10 × 10 × 15 ft high</td>
<td>Floor area all ventilated 30 × 60 ft × 6 ft 8 in. high</td>
<td>4 drying silos 9 ft 10 in. dia. × 18 ft high and 3 12 ft 2 in. high unventilated storage silos</td>
</tr>
<tr>
<td>Depth or thickness of dried layer</td>
<td>10 ft</td>
<td>6 ft 8 in.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of total area being dried</td>
<td>Quarter</td>
<td>Half</td>
<td>Three-quarters</td>
<td>Quarter</td>
</tr>
<tr>
<td>Air flow c.f.m. per sq. ft</td>
<td>25</td>
<td>19</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>c.f.m. per ton</td>
<td>125</td>
<td>95</td>
<td>75</td>
<td>130</td>
</tr>
<tr>
<td>Quantity of grain being dried (tons barley)</td>
<td>60</td>
<td>120</td>
<td>180</td>
<td>60</td>
</tr>
<tr>
<td>Drying rate per cent m.c. daily</td>
<td>0.6</td>
<td>0.45</td>
<td>0.35</td>
<td>0.65</td>
</tr>
<tr>
<td>Days taken to dry from 21-15 per cent m.c.</td>
<td>10</td>
<td>13</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Approx. fan horsepower required</td>
<td>13</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

The main conclusion to be drawn from this comparison is that on-floor drying can normally achieve a drying rate comparable with that of a vertical-flow ventilated bin, by means of a moderate rate of air flow spread over a large area of grain at shallow depth. A radial air flow bin installation, on the other hand, achieves more rapid drying of smaller quantities of grain by using a high air flow through shallow layers. The radial air flow type, in fact,
more closely approaches a batch drier, and on some farms is used as such, when much higher drying rates can be achieved.

It should be noted that the higher drying rate in the radial-flow silos is achieved partly by taking advantage of the fact that a higher rate of air flow can be economically used. This may involve a larger fan if the high drying rate is also to be applied to a large quantity of grain. Although this section deals with the rates of air flow required for drying grain, it may be noted here that only about one tenth the rate is required for the cooling of dry grain stored on floors and that the grain may be stored at much greater depth. (See *Cooling Grain to Maintain its Condition* on p. 84.)

**CHARACTERISTIC FEATURES OF CONSTRUCTION OF STORAGE DRYING INSTALLATIONS**

No attempt is made here to describe all of the many methods employed in the construction of the various types of storage driers, or to discuss structural details, some aspects of which are dealt with in *Storage, Drying and Handling Structures* on p. 133. In this section, attention is drawn to those characteristics which are of importance in securing a satisfactory performance from the viewpoint of efficient drying and easy management.

**Floor-ventilated Bins**

For most circumstances, prefabricated metal bins are preferable to any other form of construction. They are easy to erect, can be made exactly to the strength required to avoid permanent distortion, and can provide the completely air-tight walls which are an essential feature. There is a choice between rectangular bins which are nested together and carry a pitched roof, and cylindrical bins, which stand separately and have individual conical roofs. Choice between these depends partly on choice of ventilating equipment, but more on general management after drying. The nested arrangement lends itself to a fixed ventilating and conveying installation, while individual bins are more suited to the use of mobile drying and conveying equipment. There is a choice between buying a complete installation from a single firm, and buying individual components to provide a 'tailor-made' installation. Though metal bins are now usually preferable, other types are available. Where materials such as concrete staves, pre-cast concrete blocks or timber are used, it is essential to take precautions to avoid air leaks through the materials themselves or through joints. Porous materials may need some side cladding to protect the walls from driving rain.

Though it is usually undesirable to attempt to dry full bins of damp grain at a depth greater than 10 ft, it is worth while to have the bins built 15 ft high, since the additional capacity can be used for drying after the grain in the first 10 ft has been dried, and can provide relatively cheap storage capacity for grain which has been dried either in situ or in the bottoms of other bins.

Large-capacity bins are usually appreciably cheaper than small ones per ton of grain stored, but on most farms there are management disadvantages in very large bins. Provision of a spare bin to facilitate turning is not as essential as with unventilated bins, but it is an advantage to be able to turn grain after it has been dried from a high moisture content.
Floors for Ventilated Bins

The floor of a floor-ventilated silo is one of the most important components of the installation. It is essential that it be easily cleaned, and that it offers negligible resistance to air flow. Materials available include malt kiln tiles, slotted concrete blocks, wedge wire, expanded metal and perforated metal. Perforated metal is used in most 'complete' ventilated bin installations, and is also most widely used in tailor-made plants. A typical material is 16–18 gauge perforated sheet, with sufficient (about 44 per sq. in.) \( \frac{3}{16} \) in. holes to provide 20–25 per cent open space. This is easy to fix to timber joists, easy to clean, and easy to take up if this ever becomes necessary. It has a negligible resistance to air flow at the highest air speeds ever required. Some modern pre-fabricated bins have the floors made of framed panels which are simply dropped into position (Fig. 17). Louvred floors made of expanded metal have the advantage that they can be made completely self-emptying by use of the ventilating fan when grain ceases to flow by gravity alone.

Wedge wire consists of a series of parallel wedge-shaped steel strips spaced about \( \frac{1}{16} \) in. apart on the top side, and supported beneath by cross rods at about 3 in. intervals. Such a floor is only moderately strong, and needs almost as much support as perforated metal. It is sometimes used in strips supported at their edges by rebating in the concreting floor (Plate IV(b)). Such a method of construction is satisfactory for floor-ventilated bins, but not strong enough without considerable additional support, to take the heavy and concentrated loadings due to vehicle wheels which may arise in connection with drying on an open floor.

Malt kiln tiles are 1 ft square and usually have 960 holes per sq. ft. Their
resistance to air flow is higher than that of metal floors but is well within requirements where the whole floor is covered by the blocks. They are easily laid on bricks on edge or concrete piers, and there is normally no need for grouting. They are usually only attractive compared with perforated metal when obtainable at reduced price, e.g., second-hand from disused malt kilns.

Slotted concrete blocks provide one of the cheapest perforated floors available, but suffer from the disadvantage that the slots are not always completely uniform in size, and are fairly easily damaged. Resistance to air flow is not appreciable at normal air speeds where the blocks cover the whole floor area, but the free area is insufficient to permit making use of the blocks in strips.

There are many other possible ways of constructing ventilated bin floors, but most of them are more applicable to drying 'on the floor' and are considered later.

**On-floor Drying Installations**

Drying on the floor is essentially a simple system of storage drying, best suited to farms with only a small number of types of cereal crop, and an absence of complications as regards disposal. It is possible to devise an on-floor drying scheme with many partitions which enable many different parcels of grain to be kept separate; but this is usually inadvisable, since for such a need a bin system is likely to be preferable in operation, and little or no more expensive.

Information on buildings, walls and floors suited to the purpose is given on p. 144, and all that need be said here is that the building should be accessible to vehicles at both ends where practicable, and unobstructed by stanchions inside, except in the case of a wide building (e.g., over 40 ft wide) when it may be convenient to incorporate the stanchions in a longitudinal dividing wall. A convenient width for storage bays is often 24-30 ft. The main duct can conveniently be above-ground, and may be built in conjunction with a side wall in a building up to about 30 ft wide, or in conjunction with a central wall in a wider building. In suitable soil conditions it may be below ground. Methods of construction of main ducts are briefly considered later.

Among the main advantages of on-floor drying are:

- ability to receive grain at an adequate rate from the combines;
- ability to use the building for many other normal farming purposes when the grain has been removed, either between seasons, or long-term, as a result of changed farming policy;
- low capital cost.

One aim should therefore be to make the installation as easy to use for other purposes as is possible, a factor which should be borne in mind in choice of building, choice of site, construction of main ducts and, particularly, in construction of the floor.

**Air Distribution Systems for On-floor Drying**

The most important objective in designing an on-floor drying installation is to provide an effective means of delivering air into the grain in accord with the figures given in Table 1o. The air-flow arrangements should also permit
the air to be concentrated on to a very small floor area without encountering excessive resistance from the ducts or floor. There are three main ways of distributing the air, viz:

- through an air-permeable floor;
- through below-ground lateral ducts with air-permeable tops;
- through portable above-ground lateral ducts, with arrangements for delivering air through their walls.

Air-permeable Floors may be constructed of bricks laid as shown in Fig. 18. The bricks are laid as close together as practicable, without any mortar, and air passes into the grain between the individual bricks. Though such a floor can permit satisfactory drying, the amount of free air space is very small, and such floors have a high resistance to air flow. Moreover, they are fairly difficult to clean and can fairly soon become impermeable if effective cleaning is not carried out regularly. Such a floor is easy to construct, is not very expensive, and permits use of a front-loader bucket for bulk handling of the grain.

![Fig. 18. Flat floor ventilation using bricks with hessian beneath top layer](image)

Improved types of flat air-permeable floors are clearly a possibility. Materials such as kiln tiles and slotted concrete blocks appear attractive, but unfortunately they are not normally strong enough to withstand the loads imposed by the loaded vehicles which need to run over the floor when handling grain in bulk.
Below-ground Lateral Ducts with air-permeable tops have been tried, but technically satisfactory methods of construction are generally expensive. Materials such as wedge-wire may be used to form the tops of such ducts, but are not strong enough to carry loaded vehicles without additional support.

One possible method of using such materials is to lay a removable tracking over the floor to carry vehicle loads; but even if this is done, the floor needs to carry a tractor anywhere on its surface when operating a front loader.

Other types of tops for below-floor laterals include spaced timber battens with wired hessian. Such floors tend to have a high resistance and are not easy to keep clean. Most of the materials used for floors of ventilated bins either have insufficient strength, or do not provide sufficient free air space, to permit use in strips. As with above-ground lateral ducts, the following requirements must be borne in mind:

- it is inadvisable to have un-ventilated strips wider than about 30 in., especially where grain of high moisture content is to be dried. Recommended duct centre spacing for ducts about 9 in. wide is 3 ft;
- cross-sectional area of the duct at the point where air enters should be such that air speed does not normally exceed 2,000 ft per min. Thus, if ducts at 3 ft centres and 30 ft long are to provide an air flow of 15 c.f.m. per sq. ft, the amount of air supplied to a single duct will be $3 \times 30 \times 15 = 1,350$ c.f.m., and duct area at the inlet should be at least $\frac{1,350}{2,000} = 0.67$ sq. ft;
- the free air space through which air can leave the duct should be as large as possible. Too small a free air space leads to very high air speed through the grain at the points where the air passes from duct to grain, and this can easily result in a very high resistance and poor air flow;
- as a general rule, grain resistance is so high in relation to the resistance of a good duct, that there is uniform air flow from all parts of the duct. There is therefore no need to consider the use of tapered ducts, except as a means of saving materials.

These considerations apply equally to above-ground portable lateral ducts.

Above-ground Portable Lateral Ducts have many advantages. Floor construction can be very simple, and the ducts can be easily removed to leave the solid concrete floor. There is no problem in regard to entry of heavy vehicles into the building, provided that the ducts are laid as filling proceeds, and removed as the building is emptied. Chief disadvantages of using portable lateral ducts is that they make it more difficult to obtain much advantage from using a front loader. Many types of portable ducts may be used. Simple inverted timber troughs, either U-shaped or V-shaped, supported about 2 in. above floor level by means of 2 X 2 in. cross bearers, and with a hessian flap to prevent grain from being drawn into the duct through this 2 in. gap, can be quite satisfactory (Fig. 19). They are easily home-constructed. The only disadvantages are that the ducts are rather heavy, not easy to pull out of the grain when emptying a store, and occupy a fairly large amount of storage space when not in use. U-shaped ducts made of suitable welded metal reinforcing material (Fig. 20) (e.g., 1 X 3 in. by 5 and 10 gauge) and covered by hessian give excellent results as regards drying performance. There is normally no disadvantage in allowing air to escape from the whole of the duct surface, rather than only from near the floor, as is the case with most wooden ducts. Pressure measurements show that, as soon as the depth of grain above
the ducts is more than the duct centre distance (i.e., usually about 3 ft), there is a reasonable air flow at a point mid-way between ducts, and tests of grain moisture content show that it is only when grain is over about 24 per cent m.c. that there is any tendency to leave an undried wedge of grain between the ducts.

Another suitable material for portable lateral ducts is expanded metal, which can provide both the necessary strength and air permeability. Ducts constructed of such material can be made stackable, and have very few technical disadvantages. Louvred metal ducts are also satisfactory.

**Radially Ventilated Bins**

Radial-flow ventilated bins (see Fig. 21) are cylindrical in shape and have perforated walls, which may be constructed of expanded metal, perforated
metal, timber with strips of perforated metal or even of a suitable steel mesh and hessian. The air is introduced through a central perforated cylinder, and flows radially except at the top. Before ventilation is started, the top of the central air pipe must be covered with grain to a depth equal to about two-thirds the distance between the air pipe and the bin wall. If this is not done, an undue proportion of the ventilating air will escape in an upward direction. Where a number of radially ventilated bins are installed, it is convenient to have at least one fitted with a piston valve in the central pipe by means of which the effective length of this pipe may be altered to suit the depth of grain contained in the bin.

![Fig. 21. Radial flow ventilated silo](image)

The main object of radial ventilation is to allow a high rate of airflow per ton of grain with economical use of fan power, and for this reason silos should preferably be of small diameter compared with their height. With a silo 12 ft high by 7 ft 6 in. diameter, the drying cylinder should be 18 in. diameter. Such a silo holds approximately 11 tons of wheat; and an airflow of about 2,500 c.f.m. of air at the average relative humidity recommended for floor-ventilated silos (60-65 per cent) will produce a drying rate of about 1 per cent per day. Drying rate can be raised to 1½ per cent per day without excessive risk of uneven drying by reducing relative humidity of the drying air to about 50 per cent; but the higher the temperature rise employed, the more important it becomes to stop drying, and to mix the grain at the correct time. As a general guide, a farm dealing with 200 tons of corn will need 3 or 4 such drying silos, while the rest of the storage accommodation can be unventilated.
An advantage of the constructions in which the air is admitted through horizontal ducts or a perforated vertical tube, instead of through the floor, is that self-emptying hopper bottoms with a steep slope can be used. One type of bin has alternate layers of inlet and exhaust ducts arranged as in Fig. 22.

Fig. 22. Self-emptying silo with ventilating ducts

Main Ducts and Air Control Methods

There are many similarities between the requirements of main ducts and air control methods for all types of storage drying installations. Large quantities of air have to be moved over long distances, and it is essential that ducts be adequate in size, as straight as possible, air-tight, and strong enough to withstand the pressure that is developed if the fan is operated when all lateral ducts are closed. A right-angle bend very close to the fan considerably reduces efficiency, and should never be employed where a gently inclined inlet is possible.

Main ducts may be constructed in masonry, timber, steel or other convenient materials. Cost of construction may be a major item of expenditure, and cheap and effective methods are still being sought. The supply of air to individual silos in a multi-silo installation or to individual parts of a drying floor, has to be controlled by doors between the main duct and individual silos or lateral ducts. These doors must completely seal off the branches to silos or areas which are not in use. As a general rule, butterfly valves or sliding
Valves tend to be less reliable than doors which seat on a strip of foam rubber (Fig. 23). Where it is possible for the operator to walk down the main tunnel, there is nothing better than the simplest type of door, consisting of a strip of plywood or even stiff hard-board, which is simply held in position by a single turn-button type fastener, or even by being hung on a nail at the top. Provided that the door is in position when the fan starts, and is a loose fit in the frame, air pressure in the tunnel will push it in place.

A frame made of wood or light angle iron can be quite satisfactory. The essential requirement is that the face on which the door seals should not be twisted.

Where the door is located in a tunnel which is too small for the operator to enter, the best solution is usually a hinged door, operated by a wire which runs through a very small conduit (Fig. 24). When situated in the far side of the tunnel the door should be hinged at the top, and it is a good plan to set the frame at an angle, so that the door closes itself by its own weight when the wire is released. Alternatively, it may close on to a frame let into the roof of the duct, and in this case it is closed by pulling the wires. Such hinged doors need slack hinges which allow them to be pushed by air pressure on to the soft rubber seating.
In an installation with several ventilated bins or a large ventilated floor, a very high proportion of the air may be wasted if valves leak and allow the air to pass into areas where there is no grain, or where the grain is already dry.

The size of the ducting should be such that the air speed is limited to 2,000 ft per min. Above this speed, frictional losses at bends, etc., are serious, and efficiency is reduced. The area of duct required is calculated by dividing the maximum fan output in cubic feet per minute by the permissible air velocity in feet per minute, e.g., for fan with output of 15,000 cu. ft per min. cross sectional area of duct should be not less than \[
\frac{15,000}{2,000} = 7.5 \text{ sq. ft.}
\]

**Choice of Fan and Method of Warming the Air**

When choosing a fan for a storage drying installation it is usually best to select a ‘non-overloading’ type. Where only a small number of bins is ventilated a dual-stage axial-flow fan is suitable, while for a large number of bins or a large floor area, a backward-curved centrifugal fan usually provides a better solution. With the latter type, as the number of bins ventilated is increased, the total volume of air delivered rises considerably, and the flow of air through individual silos falls only slowly. The horse-power required increases as volume increases, but the effect is much less marked than with paddle-blade or, more particularly, with forward-curved fans, which are unsuitable for such a purpose.

The way in which the performance of various types of fans varies according to the floor area blown is shown in *Air Heaters and Fans* on p. 101. For a typical backward-curve non-overloading type centrifugal fan, used in an 8-silo installation filled with 10 ft of grain, performance is likely to be approximately as follows:

<table>
<thead>
<tr>
<th>Number of bins</th>
<th>Airflow c.f.m./sq. ft</th>
<th>Total*</th>
<th>Static pressure in. w.g.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28</td>
<td>2800</td>
<td>6.1</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>4800</td>
<td>5.3</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>7200</td>
<td>3.5</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>8400</td>
<td>2.4</td>
</tr>
<tr>
<td>8</td>
<td>11</td>
<td>8800</td>
<td>1.9</td>
</tr>
</tbody>
</table>

* assuming 100 sq. ft floor area per bin

In choosing a fan for an on-floor drying installation, it is practicable to manage with a slightly lower fan output per ton with large plants than with small. Table 11 provides a general guide to minimum levels at which to aim. Higher air-flows can be used with advantage where large fans can be economically provided.

Thus, for a 200 ton plant a fan capable of delivering 14,000 c.f.m. against 2 in. w.g. (whole area), 11,000 c.f.m. against 3 in. w.g. (half area), or 7,000 c.f.m. against 5 in. w.g. would be suitable.


### Table 11

**Airflow for on-floor drying**

<table>
<thead>
<tr>
<th>Size of Installation</th>
<th>Whole area</th>
<th>Half total area</th>
<th>Quater area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air-speed c.f.m. per sq. ft</td>
<td>Equivalent c.f.m. per ton</td>
<td>Resist: in. w.g.</td>
</tr>
<tr>
<td>Small plants up to 250 tons</td>
<td>10</td>
<td>70</td>
<td>1 1/2-2</td>
</tr>
<tr>
<td>Medium sized plants</td>
<td>9</td>
<td>65</td>
<td>1 1/2-2</td>
</tr>
<tr>
<td>Large plants over 500 tons</td>
<td>8</td>
<td>60</td>
<td>1 1/2-2</td>
</tr>
</tbody>
</table>

The relatively wide range of resistance to air flow indicated by the table is due partly to variations in losses in main and lateral ducts.

The maximum temperature rise that is normally required for storage drying installations is about 10°F, though a little more may be useful in very cold and foggy conditions. The need for maximum temperature rise very seldom coincides with a need to blow the whole floor area of the installation, and in practice it is usually satisfactory to provide for a 7°F rise over about three-quarters of the total floor area in the case of a large plant.

For small installations, where an adequate power supply is available, electrical heater elements, which can be switched on in stages, and are normally located on the inlet side of the fan, are both convenient and economic. About 3 kW per 1,000 c.f.m. provides for a temperature rise of 10°F. In a typical arrangement, the heater is divided into units of different size, which can be used either independently or together. For example, a heater of 21 kW capacity may be arranged in groups of 3, 6 and 12 kW, thus making it possible to switch on in 3 kW increments throughout the complete range. The whole of the installed heater capacity is very seldom needed. It is only required when the fan is operating at full capacity in conditions of high relative humidity.

For large installations, where an adequate electricity supply may be a problem, and operating cost with an electric heater would be substantial, the best solution is likely to be an electrically operated fan, and an oil-fired heat exchanger unit. Such an installation is likely to be well suited to storage driers of upwards of about 250 tons. For smaller installations where there is only an adequate electricity supply, the use of a bottled gas heater unit may be the best solution.

Direct oil firing is not recommended for storage driers, since any malfunctioning of the burner may not be detected and can result in tainting of the grain.

A common and quite satisfactory method for all normal conditions is utilization of the waste heat from the internal combustion engine which
drives the fan. As a general rule the temperature rise provided is quite adequate and may indeed be excessive, if precautions are not taken to bleed in unheated air when necessary. The normal method of installation is to draw part of the air into the fan from the engine house, and part directly from outside, the proportions being fully adjustable. When the whole of the waste heat is used and the fan is blowing only a small floor area, temperature rise can exceed 10°F. At the other extreme, on full air flow, temperature rise may be only about 4–5°F.

For easy checking of the temperature rise provided by any method of heating, it is advisable to install a pair of direct-reading dial thermometers, one with its bulb near the fan inlet and the other in the main duct (Fig. 25). This enables the effect of the heater control to be easily read.

Fig. 25. Centrifugal fan and heater unit showing layout of thermometers

A direct-reading hygrometer installed in the main duct can be useful in indicating the correct temperature rise if checked two or three times a day, and used in conjunction with tests of grain moisture content in the dried layer.

Further information on fans and heaters is given on p. 98.
OPERATION OF STORAGE DRYING INSTALLATIONS

It is essential, when managing any kind of storage drying installation, to understand the principles of drying, which have already been outlined. Principles of operation are the same for all kinds of storage driers. It is therefore convenient to deal with the operation of floor-ventilated bins in some detail, and only to discuss aspects of operation of other types where they are appreciably different.

VENTILATED BIN MANAGEMENT

One of the essential requirements of a storage drying installation is that nothing must be done to interfere seriously with an even flow of air through the whole of the grain. This is particularly important when unusually wet grain is being dried.

The most common causes of uneven air flow in a well-designed installation are uneven filling, and the presence of dust, greenstuff and other contaminants in dense pockets.

It is therefore important, when grain is particularly wet, to fill evenly and either to remove contaminants or to take care to spread them as evenly as possible. Wet grain in bulk can easily be made appreciably denser in some parts than others by such practices as dropping the grain on the same spot for long periods by means of a conveyor. When loading a bulk store, conveyors should be arranged to sprinkle the grain lightly over a large area, or should be moved frequently if practicable. Conveyors should accordingly be chosen and used with such problems in mind. Where wet grain also contains a large amount of dust, greenstuff or other contaminants which tend to reduce air flow or to set up heating, it is best to remove it before drying, though this may not be practicable with some types of on-floor drying installations. With ventilated bins, use of a good aspirating type pre-cleaner should be normal practice, and the cleaner should only be by-passed if the grain is exceptionally clean.

Drying should begin as soon as the bin floor is covered with grain, and should continue until the moisture content has been reduced to a safe storage level. The most important control instruments are a grain moisture meter and a sampling spear which enables samples of grain to be taken from the dried layer. The moisture content of the grain in the dried layers is the most reliable indication of the success or otherwise of the operator in achieving, on average, the required conditions in the air blown through the silos.

Reduction of moisture content to 14–15 per cent is recommended for long term storage (Table 3, p. 18). Grain at this moisture content is in equilibrium with air of between 65 and 75 per cent relative humidity, the exact relationship depending on kind of grain, temperature and whether the grain is picking up or giving out moisture. Many farmers wish to store at higher moisture contents, and, as indicated on pp. 17–18 and pp. 83–90, this is practicable in ventilated bins or floor stores, provided that the operator is prepared to cool the grain thoroughly after drying, as explained on p. 84, and to check the condition of the grain regularly, by turning on the fan and going to the top of the bin to see if the air that emerges shows any sign of heating.
With a weekly check of this nature, after drying is completed, it is practicable
to store clean, sound grain at 17-18 per cent m.c., at normal winter tempera-
tures. In order to achieve such a moisture content, an average relative hu-
midity in the region of 80-85 per cent is needed, so little or no warming of the
atmospheric air is required during the normal harvest season.

The most common errors made by farmers, who are new to storage drying,
are use of too high a temperature, and stopping the drying process before
drying is complete. A high temperature rise is especially undesirable in a
cold, wet harvest. The grain in the silo may, in the early stages of drying, be
not only very wet but also very cold. If at this stage a temperature rise of say
20°F is used, the effect is that the warm moisture-laden air is rapidly cooled
as it passes upwards through the wet grain, and in these circumstances
moisture may be deposited in the upper layers. This makes subsequent drying
operations unnecessarily difficult. The only satisfactory way of dealing with
very damp grain is in shallow layers. When empty bins are available it is
best to spread it over several floors at a depth of no more than 5 ft.

In these circumstances, where the ventilated bin plant is used as a batch
drier, and the grain is turned and mixed immediately afterwards, it is prac-
ticable to make use of a temperature rise of up to about 20°F if the plant is
capable of providing this. Even in these circumstances, however, it is best to
blow for at least half a day with only slightly warmed air, to ensure that the
grain is warmed right through before the more rapid batch-type drying is
begun.

The general effect of reducing grain depth is indicated by Table 12, which
relates to the drying of 20 tons of barley. If dried in one bin at 10 ft depth,
drying takes more than twice as long as it does if the grain can be spread over
two bins.

| TABLE 12 |
| Effect of grain depth on drying rate |

<table>
<thead>
<tr>
<th>Airflow through each silo</th>
<th>21 ft per min</th>
<th>24 ft per min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units of electricity used per hour</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>Drying rate: average percentage removed in 24 hrs</td>
<td>0.5%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Time needed to dry to 14% m.c.</td>
<td>14 days</td>
<td>6 days</td>
</tr>
<tr>
<td>(a) from 21% m.c.</td>
<td>8 days</td>
<td>3½ days</td>
</tr>
<tr>
<td>(b) from 18% m.c.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where grain is rapidly dried by use of a temperature rise well above 10°F,
it is necessary to interrupt drying while the top is still quite damp, so that the
average moisture content of the mixture of top and bottom will be a little
higher than that required for storage. After mixing, a short blow with air of
the correct relative humidity will soon even up the moisture content.

Care should be taken to level off the surface of damp grain, so that the
whole silo may dry evenly. Uneven grain depth will increase the time taken
to complete the drying process. Some types of conveyor createdense pyramids
of grain when the silo is being filled. These should be stirred and levelled off.
The fact that resistance to airflow falls considerably with a reduced depth of grain must be borne in mind when a number of silos with varying depths of grain are being ventilated at the same time. It would be a mistake to try to dry a full silo of very damp grain at the same time as a half-filled silo of drier grain, since a high proportion of the air would pass through the half-filled silo. In such circumstances the damp grain should, if possible, be put into two silos, and the valve to the silo containing the drier grain closed until the very damp grain is reasonably safe.

For a given depth of grain in a single silo, the amount of air that is passed through will naturally be greatest if the valves to all other silos are closed. With all installations, however, the output of the fan in such conditions will be considerably less than its total output when several silos are being ventilated.

There are, broadly, two main methods of controlling the heater bank that warms the ventilating air and reduces its relative humidity. By one method an attempt is made to keep the relative humidity constant throughout the drying period; the other is to operate with a steady temperature rise that is maintained for a period of 24 hours or more, and is designed to secure the correct average relative humidity. This latter method, intelligently followed, has been found simple to operate and effective in practice. Where it is used, the average temperature rise required naturally varies with atmospheric conditions, and, where the aim is to dry down to 14–15 per cent m.c., the following table may be used as a guide.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Temperature Rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>In cold damp weather</td>
<td>8–10°F</td>
</tr>
<tr>
<td>In hot dry weather</td>
<td>0–6°F</td>
</tr>
<tr>
<td>In intermediate conditions</td>
<td>6–8°F</td>
</tr>
</tbody>
</table>

In extreme conditions, when atmospheric temperatures are very low and humidity is very high in late autumn, there may be a case for using temperatures up to 13°F above atmospheric, when drying is continued throughout the night; but such conditions are exceptional, and there is normally no need to design installations to provide such a temperature rise at maximum air flow. For drying to a higher final moisture content, lower temperature rises will suffice.

The above rough guide on required temperature rise is adequate for most purposes, since any slight under-drying or over-drying in the early stages may be remedied in the final stages, when grain moisture content of the dried layer can serve as a guide. It is not usually worth while to attempt more accurate control, owing to the rapid fluctuations which occur in atmospheric temperature and relative humidity during any period of 24 hours. Where an attempt is made to obtain constant relative humidity by means of manual control of the heater bank, it is necessary to make adjustments at least twice daily. A hygrometer must be used to measure the relative humidity of the atmosphere, and the temperature rise required is then read off from tables. There are, however, automatic regulating devices which incorporate a humidstat and the necessary electrical relays. Such devices need regular adjustment. They also require the installation of a rather larger heater-bank, since the latter does not operate at full capacity during the daytime. The devices are convenient for a farmer who cannot personally supervise the operation of the drier, since they prevent the over-drying of any part of the grain; but the virtue of using a steady temperature rise lies in the fact that adoption of such a system usually
This platform drier is situated in the implement shed, and machinery is stored on it during a great part of the year.

Ventilated silo installation with bulk unloading from a twin leg high-capacity elevator which forms part of the system for receiving, cleaning or turning grain (Photograph: Conder Engineering Co. Ltd.)
Outdoor ventilated bins arranged on radius of circle to facilitate use of augers for filling and emptying (Photograph: Massey-Ferguson (Farm Services) Ltd.)

On-the-floor drying and storage

The store is shown partly unloaded, with lateral removed, leaving a flat unobstructed storage area. The main air duct, with outlets to laterals, runs down the right-hand side of the building (Photograph: Farmer & Stockbreeder)

Unloading by means of a suspended auger has revealed three lateral ducts, the outer one being uncovered to show the welded mesh structure, impervious cap and hessian cover. Drain pipes, which can be sealed when not in use by means of plastic buckets, serve as air outlets from the main duct (Photograph: Farmer & Stockbreeder)

Plate II
Air-tight high-moisture grain store with sweep arm auger unloading (Photograph: Automatic Storage Co. Ltd.)

Mobile equipment for grain chilling (Photograph: Henry Simon Ltd.)
It is possible to control the flow of air to individual silos by removable hard-board panels, one of which has been removed to permit ventilation of this silo.

Complete self-emptying of floor-floor bins is possible with this type of floor, using the ventilation fan. (Simplex of Cambridge)
Mobile auger conveyor (Photograph: Gordon Felber & Co. Ltd.)

Auger intake guard (Photograph: National Institute of Agricultural Engineering)

Mobile auger collector (Photograph: Juddleigh Spraying Co. Ltd.)
Chain and flight conveyor (Photograph: Bentalls of Maldon)

Sampling spear (Photograph: National Institute of Agricultural Engineering)

PLATE VI
(a) Infra-red meter (Photograph: National Institute of Agricultural Engineering)

(b) In this electric meter, the milled grain contained in the small test cell is compressed by the screw clamp, but compression cannot be excessive.

(c) Capacitance type meter with weighing pan (Photograph: National Institute of Agricultural Engineering)

(d) A hygrometer-type grain moisture tester. The ventilating holes at the lower end of the stem can be closed by twisting the dial head.

Plate VII
(Left) Adult saw-toothed grain beetles on wheat

Grain weevil (actual length about \( \frac{1}{8} \) in.)

Applying a residual insecticide by knapsack sprayer

PLATE VIII
DRYING GRAIN IN BULK

results in the desired final moisture content with a minimum of control gear and instruments. Where the steady temperature rise method is employed, any temporary over-drying that occurs in the bottom of the silo during a warm day is automatically compensated for during the night, when there is a tendency for the ventilating air to be too damp.

There is no need for constant supervision once the grain is in the silos, and the plant can be left for several hours between occasional visits from the operator to see that drying is progressing satisfactorily. It is advisable to turn the grain once, after drying a batch which has been really damp, so that any pockets of grain which are not thoroughly dried may be distributed.

Cooling

With all types of ventilated bins or on-floor drying installations the grain is usually cool when drying is complete. If not, it is important that, once drying with heated air has been completed, the grain should be cooled to 60°F or below by blowing it with unheated air in accordance with the principles outlined on pp. 83-87.

Management of On-floor Driers

The main respects in which management of an on-floor drier differs from that of a floor-ventilated bin plant is that it is less easy to isolate areas of very damp grain for special treatment, and much more difficult to dry in two distinct stages, with a turning operation in between. For this reason, and because air is not delivered over the whole floor area, on-floor driers tend to be slightly more difficult to manage in a wet season. However, the relatively shallow drying depth makes it possible to succeed, providing that specially damp areas are carefully noted and are given special attention.

In conditions when it is impossible to avoid loading the store with a large amount of grain at high moisture content, it is essential, in the early stages of drying, to avoid over warming the air. As with ventilated bins, the natural tendency is to use the maximum amount of heat, but this is the most certain way of causing moisture to condense in the upper layers, and there to form a hard layer which is almost impossible to dry without physically breaking it up. Formation of such a layer does not take place if the rules already given for control of temperature rise are followed. If a hard layer does form near the surface of the grain, it is worth while to break it up with a fork or a hay rake.

A suitable drying depth is 6–8 ft though it is quite possible with grain of below 20 per cent m.c. to dry successfully at greater depth. It is, of course, essential to keep the top of the grain reasonably level during drying, but afterwards there is nothing to prevent dried grain being heaped up, provided that the walls are strong enough to resist the additional thrust.

The grain can be effectively loaded by means of one or more 3 in. augers but it is easier with a large-diameter trolley-mounted machine, which is more easily moved to keep the top level. The grain may be tipped into a hopper at the foot of a 5 in. auger and delivered at a rate of well over 20 tons per hour. When small augers are used, they may be supported by roof members.

When emptying, lateral duets can be removed as they are uncovered, and
a front loader can then be used, either for direct loading or in conjunction with augers. Farmers who favour below-floor ducts do so because of the greater ease of using a front loader both for filling and emptying.

Some farmers, with large stores or with a very narrow store, install a reversible horizontal conveyor down the centre of the building and use it in conjunction with a reception pit or area at one end of the building. Such an arrangement permits effective use of a cleaner either before or after drying. However, such additions tend to remove one of the main attractions of the system, i.e., low cost.

**Management of Radially Ventilated Silos**

Successful drying of grain in radially ventilated silos depends on securing a uniform air flow all round the drying cylinder. For this reason it is very desirable to fill the cylinder at the centre, so that the grain falls uniformly all round the central drying tube. A disadvantage of the radial-flow system is that it is usually not practicable to give separate treatment to layers of different moisture content at different heights in the silo. For this reason, among others, it is desirable, in such conditions, to turn the grain from one silo to another partway through drying. Where the grain is to remain *in situ* it is necessary to check the progress of drying by sampling from near the edge fairly often as drying nears completion.

The radial flow method permits the achievement of high drying rates by means of a high air flow. It is also possible to achieve rapid drying by use of a higher temperature and a batch drying system.
Cooling Grain to Maintain its Condition

It is possible to control and prevent insect infestation in dry grain, and also to prevent mould growth in grain of moderately high moisture content, by lowering the temperature of the grain.

When considering the cooling of grain by artificial means, it is necessary to distinguish between:

(a) cooling dry grain with ordinary air to render it safe from insect attack, i.e., to a temperature of 63°F or below;
(b) chilling damp grain with refrigerated air to prevent the growth of moulds. For this, the temperature must be reduced to 30–45°F, according to the moisture content of the grain.

To avoid confusion, it is proposed to use the term 'cooling' for (a) and 'chilling' for (b).

COOLING DRY GRAIN TO PREVENT INSECT INFESTATION

Warm weather at harvest time, or inadequate cooling in the drier, often results in grain being put into store at a temperature of 70–85°F or higher. Insects can breed rapidly at these temperatures, and the heat they produce will lead to the development of 'hot spots', with resultant mould damage and sprouting grain. In addition, high temperatures speed up grain deterioration.

Since it is difficult to detect insects or hot spots in large grain bulks, serious damage may result before their presence is realized. This danger can be overcome by cooling the grain with normal untreated air, by means of an in-store aeration system consisting merely of ducting and fans. Protection against insect infestation can be obtained by cooling the grain to 63°F or below, at which temperature the rate of development of all common insects is reduced to negligible proportions (see Principles of Grain Drying and Storage, p. 17). In practice it is usual to cool the grain, whenever the weather permits, during the months following harvest. The aim is to obtain a temperature as low as is conveniently possible, which should be less than 63°F. This is in case a warmer area is left in part of the grain due to accumulations of dust or poor duct positioning. In East Anglia it is common to reduce the highest temperature in a bulk of grain to less than 54°F.

It is possible, using this form of aeration, to store bulk grain from harvest until the following spring at a moisture content a little higher than usual, e.g., 16 per cent (Fig. 4, p. 18). However, as it is difficult to control the moisture content of grain entering a bulk store to an exact figure, it is safer to aim at the slightly lower moisture content of 15 per cent.

A Simple Aeration System

In a normal aeration system, a fan is used to force air along perforated ducts, on or below the floor of the store or at the base of a bin. In passing through the grain, the cool air picks up heat from the grain and the warmed air then
passes through the surface of the bulk and finally out of the store through windows, roof or ventilators. Alternatively, the air may be drawn downwards to the duct and exhausted by the fan to the outside of the building.

**Air Flow**

For a given temperature difference between air and grain, the rate of cooling is proportional to the rate of air flow. The installation is usually arranged to provide an even supply of air through the grain bulk, at a rate of 5–10 c.f.m. per ton of total storage capacity. In large installations of bins or silos a rate of 2–3 c.f.m. per ton of total capacity may be adequate; but in smaller flat stores higher rates may be needed. These air flows are far less than those used in drying (see *Drying Grain in Bulk*, p. 65), so that an in-store aeration system is very economical in fans and power. The cost of electricity for cooling 1,000 tons of grain is about 30s.

**Fans**

The choice of fan is largely determined by the pressure needed to force the required amount of air through the grain.* This pressure is in turn largely dependent upon the distance the air must travel through the grain. In flat stores, the distance may be short and the pressure low, whereas in deep silos, a high pressure is required to force the air through the grain. As fans produce a considerable amount of heat at high pressures, in deep grain stores or bins the air should preferably be sucked through the grain to the fan, to avoid warming the grain with fan heat.

**Ducting**

Ducting may be constructed from wood, punched or expanded metal, or welded steel mesh covered with hessian as described on p. 70. It may be positioned on or below floor level.

The positioning of the ducting in the store determines the persistence of slow-cooling areas of grain (Fig. 26). These occur along the lines of greatest distance between the duct and the surface of the bulk (L in Fig. 27), in areas where natural cooling is slow, i.e., 2 ft or more from a grain face.

The ducts should be placed at the base of the store in such a position that the ratio of the longest air path from the duct to the grain surface (L in Fig. 27) to the shortest air path (S in Fig. 27) does not greatly exceed 1:5:1:0. In most level-loaded stores, therefore, the ducts are spaced so that the distances between ducts do not exceed the depth of the grain.

**When to Aerate**

Direct aeration of dry grain with air of high relative humidity will cause the grain to absorb moisture and may result in mould growth. To avoid this, the grain is normally aerated only when the relative humidity of the air is at 75 per cent or below. This usually restricts the aeration to limited parts of the day only. For this procedure, a method of measuring the relative humidity

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* See *Principles of Grain Drying and Storage*, p. 25, for information on resistance of grain to airflow.
must be available, e.g., a wet-and-dry-bulb thermometer or an accurate hair hygrometer. Alternatively, automatic switches operated by the relative humidity of the air can be incorporated in the fan circuit.

![Diagram](image)

Fig. 26. Cooling stages in a large floor store with central cooling duct

![Diagram](image)

Fig. 27. Spacing of aeration ducts

COOLING PROCEDURE

Cooling is most efficiently carried out in stages, to take advantage of progressively cooler weather following the harvest (Table 1, p. 8). The main part of the cooling is carried out as soon as possible after loading the stores, and further aeration periods then continue as the autumn and winter weather...
becomes colder. The total number of hours of aeration required is likely to be 100 to 120 at an air flow of 5 c.f.m. per ton of grain, depending on the persistence of warm spots, which in turn depend on the shape of the bulk, and the duct positions.

**Checking Progress**

It is advisable to check the efficiency of a newly installed aeration system. The main points to watch are:

- is all the air that has passed through the grain exhausted to the atmosphere without the possibility of its being re-circulated through the grain? Recirculation of warm air must be avoided;
- is the air distributed evenly through the grain?

A method of checking the rate and distribution of air flow is to use an air flow meter which is sufficiently sensitive to indicate velocities of as low as 0.5 ft per minute as the air passes through the surface grain. One such instrument has been developed (see Appendix for references), based essentially on the rate of movement of a film of detergent along a wide glass tube.

An even air flow over the entire surface indicates even cooling. Large variations should be corrected, since uneven air flow causes uneven cooling. This correction may be carried out by adding more grain to areas of excessive air flow and removing it from areas of low air flow. Fig. 26 shows the cooling pattern found in a peak-loaded store with a single central duct.

The best method of measuring the effectiveness of the installation is to measure the temperature of the grain at intervals during the cooling process. This can be done by means of thermocouples or other temperature-sensitive devices (see p. 129) inserted in the grain bulk. This may be difficult in deep stores unless a permanent installation is provided, such as is sometimes installed in bins, before the grain is put in.

If a permanent temperature measuring system is installed in an aerated bulk grain store, and it is certainly advisable in a large installation, the sensitive elements must obviously be placed where the warmest grain is likely to be encountered. In bin storage, where the grain depth exceeds the width, the temperature-measuring devices are best placed centrally. If the air is blown in an upward direction a probe inserted centrally 4 to 6 ft from the top is likely to record the highest temperatures. If the air is drawn downwards in a similar bin, the warmest grain will be found at about 2 to 6 ft above the duct. In this case two instruments should be installed, at heights of 3 ft and 6 ft above the duct. In a flat store, where the width of the bulk exceeds the depth, the position of the warmest areas will be towards the sides of the store if there is one central duct (Fig. 26), or equidistantly between the ducts if there is more than one duct. As in a bin, if the air is blown upwards the warm areas will be superficial and may be measured by thermometers on probes, preferably wooden, pushed in from the top. If the air is drawn down, the warm spots will be deep in the bulk and will require a built-in apparatus. As it is difficult in a short account to cover all circumstances of duct placing and bulk geometry, the positions of the warm areas may not always comply with the general statements above, and the requirements of each store should be considered individually.
WHERE EXISTING BINS OR STORES HAVE BEEN FOUND TO BECOME INFESTED, OR WHERE AN INFESTATION IS FEARED, IT IS USUALLY WORTH WHILE TO INSTALL AIR DUCTING. SINCE THE NUMBER OF INSECTS IN A COOLED BULK INCREASES ONLY GRADUALLY OVER A PERIOD OF MONTHS, MINOR RESIDENT INFESTATIONS LEFT IN THE CREVICES OF A STORE BECOME LESS EACH YEAR UNTIL THE BUILDING IS VIRTUALLY FREE FROM INSECTS. THIS DOES NOT MEAN, HOWEVER, THAT THE USUAL STORE HYGIENE CAN BE NEGLECTED, AS ANY HEAVY INFESTATION IN A HEAP OF GRAIN LEFT FROM A PREVIOUS YEAR MAY MIGRATE INTO NEW GRAIN AND CAUSE HEATING IN A VERY SHORT PERIOD.

CHILLING GRAIN TO MAINTAIN QUALITY AND PREVENT GROWTH OF MOULDS

THE CHILLING OF HIGH MOISTURE GRAIN TO PREVENT MOLD GROWTH IS DISTINCT FROM THE COOLING OF DRY GRAIN WITH ORDINARY AIR TO PREVENT AN INSECT INFESTATION ARISING, AS ALREADY DESCRIBED. ONE SIDE EFFECT OF CHILLING IS TO PREVENT ALL GRANIVOROUS INSECTS FROM BREEDING AND CAUSING HOT SPOTS. MITES, HOWEVER, WILL ONLY BE CONTROLLED IF THE TEMPERATURE IS BELOW 40°F.

AT PRESENT CHILLING IS NOT WIDELY USED FOR PRESERVING GRAIN IN BRITAIN. THERE ARE INDICATIONS, HOWEVER, THAT IT MAY BECOME MORE WIDESPREAD IN THE FUTURE, ESPECIALLY IF THE PRESENT TENDENCY CONTINUES FOR LARGER QUANTITIES OF GRAIN TO BE GROWN AND STORED WITHOUT DRYING ON FARMS.

SAFE CONDITIONS FOR CHILLING

WHEN THE TEMPERATURE CAN ONLY BE REDUCED TO AND MAINTAINED AT 45°F, THE MOISTURE CONTENT OF THE GRAIN PLACED IN THE STORE SHOULD NOT EXCEED 20 PER CENT, ESPECIALLY IF THE FULL GERMINATIVE ENERGY OF THE GRAIN IS TO BE RETAINED. AT A MOISTURE CONTENT OF 22 PER CENT, A TEMPERATURE BELOW 35°F MUST BE MAINTAINED TO PRESERVE GERMINATION. ALLOWING FOR IMPERFECTIONS WHICH ARISE IN FARMING PRACTICE, RECOMMENDED STORAGE REQUIREMENTS ARE BRIEFLY SUMMARIZED IN TABLE 13.

<table>
<thead>
<tr>
<th>Grain moisture content per cent</th>
<th>Storage temperatures °F</th>
<th>For no deterioration in two months’ storage</th>
<th>For freedom from mould, with slight impairment of germinative energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>55</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>45</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>40</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

CHILLING MUST BE RAPID IF THE GRAIN IS TO BE PREVENTED FROM SPOILING. THE DAMPER THE GRAIN, THE FASTER IT PRODUCES HEAT AND THEREFORE THE MORE RAPIDLY
it must be cooled. Whereas grain below 20 per cent moisture may be chilled over a period of a week, grain of 20-22 per cent should be made cold within 3 days. Because of the need for speed, chilling relatively small batches of 30 to 100 tons is probably the most economical; each batch may form one section of a bulk of 400 to 1,000 tons or more.

Even with chilling below 40°F, grain in excess of 22 per cent moisture should only be stored for short periods and should be dried to a safe level as soon as possible, since, even if mould damage is negligible, damage to germination will result. Once chilled, the grain must be kept cold by further refrigeration. The interval between chillings depends on ambient conditions, effectiveness of insulation, and on any tendency of the grain to generate heat. As a general guide, the maximum interval is likely to be 1-2 weeks in early autumn, but may lengthen to 1 month in a cold spell in winter.

**Bins or Floor Stores**

Chilling can be used both for storage in bins and on the floor.

In practice, several bins may be served by one chilling unit, moving from one bin to the next as they are filled. Alternatively, two or more bins may be chilled at the same time. The use of unlagged metal bins is not advised for long periods of storage because of heat penetration into the bin. Frequent re-chilling is required in such a bin and it will take almost as long to re-cool the grain against the sides of the bin as it took to chill the entire bin. In considering insulating qualities of bins, it should be remembered that 0.5 in. thickness of a good material, such as expanded polystyrene, has the same 'U' value as 9 in. of brickwork. For economic reasons the bins should not exceed 20 feet deep, as, at depths greater than this, the power consumption is very high at the air flows required.

Large floor stores of over 400 tons in a single bulk are probably the most efficient, and re-chilling is only necessary for a few hours per week or per fortnight according to the moisture content of the grain and the material from which the building is made.

**Chilling Capacity**

Because of the difference in storage conditions, each installation should be designed separately according to requirements. Factors which determine the size of chilling unit are:

- daily rate of grain intake;
- moisture content at which grain is to be stored;
- number of batches or total capacity to be maintained in a suitably chilled state during storage;
- temperature differential to be expected at the 'worst normal' conditions;
- type of store as regards insulating properties, etc.

For example, a plant may need to be designed for the following conditions, some of which are, of course, assumed for design purpose:

- daily intake of 25 tons, to be stored in batches of 50 tons;
- total storage capacity 400 tons in a compact block in bins, housed in a building clad with asbestos;
- ambient temperature at harvest 75°F;
- storage moisture content 20 per cent, requiring a storage temperature of 40°F for no deterioration.
For complete safety, though it is not essential to chill a particular batch of 25 tons completely in 24 hours, the equipment should preferably have the capacity to do this. Chilling of new batches must not fall behind schedule and so allow spontaneous heating of the grain to occur, since this can completely upset calculations of required refrigeration capacity. This means that the amount of heat to be dissipated, ignoring heat gains due to poor insulation and heat production by the grain, is:

\[
25 \times 2240 \times 0.48 \times 35 \text{ per 24 hours,}
\]

or approximately 40,000 B.t.u. per hour. The actual load will depend, to an appreciable extent, on the degree of insulation and efficiency of the complete installation, as well as on the weather conditions. It can be up to approximately double the figure calculated above. The limited experience available to date indicates that in practice such a load will call for a compressor driven by a 3-5 h.p. motor, a condenser fan with a \( \frac{1}{2} \) h.p. motor, and a chilled air delivery fan driven by a motor of 1-2 h.p.

At the present stage of development it is wise to err on the safe side and, bearing in mind that grain moisture content may well be appreciably above the design 20 per cent m.c., it is advisable to reckon on a unit using a total of about 8 h.p.

In the present stage of knowledge it is advisable to install a chilling unit that is over- rather than under-powered and to use a variable speed fan with an over-powered motor. The initial cooling to 45-50°F could be carried out at maximum air flow, then later the temperature may be brought down to a lower storage temperature, e.g., 40°F, by reducing the air speed.

For a hundred ton batch in a bin or in floor storage under 20 feet deep and at 20 per cent moisture, a compressor of about 5 h.p. is normally adequate to chill the grain in about 4 days at an airflow of about 10 c.f.m. per ton of grain, i.e., a total air flow of 1,000 c.f.m. This chilling period could be extended safely to 7 days for grain below 20 per cent. A similar mass of grain at 20-22 per cent would require pro rata a larger compressor and a higher air flow to chill the grain in less than 3 days in which chilling should be completed at this higher moisture level.

**Drying by Chilling**

Appreciable drying will only occur if the chilled air is reheated before being passed into the grain, for example, using the heat produced by the circulating fan. If the air is not reheated by about 3°F, then the grain around the duct will become wetted. It is true that grain can be dried by chilling but, if this is attempted, the economy in fuel consumption as compared with drying will be lost, since the unit will need to be run almost continuously. Drying by refrigeration is extremely inefficient since air at 40°F will only hold one sixth of the water that it holds at 90°F.

**Operational Points and Difficulties**

At low temperatures approaching freezing point the evaporator coils of the

\* For variation of specific heat with moisture content, see Appendix, Table A4.
chilling unit may ice up frequently, so reducing the air flow. Automatic de-icing systems can be used to prevent this.

An air-cooled condenser is preferable to one cooled by water, since mobility of the units for use in several bins or on several ducts is impaired if a mains water supply is necessary.

Grain should be harvested as dry as possible, since less stringent temperature conditions are required and a high safety factor is obtained.

The chilling unit should be over-powered rather than under-powered and should preferably be supplied with a variable speed fan. In this way variation in the rate and degree of cooling is obtainable if necessary.

Chilling of a grain bulk should be completed at night to ensure maximum chilling and also to bring the grain against the walls to the lowest possible temperature.

The air ducts should be large enough to prevent the air velocity in them from exceeding 2,000 f.p.m.

The air flow necessary to cool a bulk of grain in 24 hours is about 30 c.f.m. per ton of grain. If cooling is to take three days, only 10–15 c.f.m. per ton is required.

The spacing between the ducts depends mainly upon the grain depth and the surface contours. In a level loaded store, the duct spacings should not exceed the grain depth.

Note: This rule applies to grain cooling and chilling and is not applicable to grain drying on the floor (see p. 70).

The grain surface of a store should be as even as possible, since sudden variations in the grain surface will produce slow cooling areas.

Chilling of a bulk of grain should be continued until the entire surface has been cooled. Thermometer probes should be inserted into areas where slow cooling is suspected. In bins, this is where the sun or atmospheric heat is warming the sides.
Airtight Storage of High Moisture Grain

The moulds that develop on damp grain stored under normal conditions need oxygen for their growth, and, if air is excluded, they will die or become inactive. Grain stored in sealed silos will, therefore, remain mould-free.

In Britain, when airtight storage was first considered on an experimental scale in 1952, it was hoped that it might delay or dispense altogether with the need for drying, and that grain so stored would be suitable for all purposes. Results of tests and practical experience have shown that, although grain stored in airtight bins remains free from mould, certain changes take place which make the grain unsuitable for milling, malting or seed, although it is satisfactory for animal feed.

Mould Development in High Moisture Grain

Development of moulds and other micro-organisms in grain, and their control, can be related to three different levels of moisture content:

<table>
<thead>
<tr>
<th>Moisture Content of the Grain</th>
<th>Micro-organisms Controlled by</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Up to 15 percent</td>
<td>Low moisture content</td>
</tr>
<tr>
<td>(ii) 15 to 25 percent</td>
<td>Drying; ordinary airtight storage; refrigeration</td>
</tr>
<tr>
<td>(iii) 30 to 40 percent</td>
<td>'Silage' techniques (an unstable form of airtight storage)</td>
</tr>
</tbody>
</table>

Experience so far suggests that different species of micro-organism are concerned at the three levels. Those growing at moisture contents of up to 25 per cent are mould fungi that require oxygen for their growth, and die in its absence. The organisms (probably bacteria) active at the higher moisture levels are less dependent on oxygen, but flourish under acid conditions such as develop during the production of silage.

Storage in Air-Tight Bins

In recent years sealed silos have become increasingly used for the storage of high moisture barley for feeding to livestock, and this development is likely to continue. Sufficient is already known about the method to give a general account of what is likely to take place during such storage, but certain problems have still to be solved.

Changes Taking Place in the Grain

As long as the bin is airtight, hermetically stored grain remains bright in colour and free-flowing, even at relatively high moisture contents (25 per cent). It does not become visibly mouldy as long as air is excluded. At moisture contents of 17 per cent and above, there is a certain amount of
fermentation, and the grain develops a sour-sweet smell and bitter taste, especially at high moisture levels or on prolonged storage.

At moisture contents above 25 per cent the grain may become dark in colour and rather soft. Towards the bottom of the bin there is sometimes a certain amount of compaction due to pressure on the relatively soft grains. This is quite different from the ‘caking’ due to mould growth, and the grain mass usually breaks up easily when touched. In tall bins however, the settled grains may produce ‘bridging’ which can cause difficulty unless there is a special arrangement for unloading.

**Changes in the Atmosphere**

The rate at which oxygen is used up and carbon dioxide produced depends mainly on the moisture content and temperature of the grain. Only a few days are needed, at moisture contents of 22 per cent and above, before all the oxygen is removed.

With grain at moisture contents over 15 per cent the carbon dioxide produced in excess of the oxygen used up, due to fermentation, results in appreciable pressure inside the bin. In commercial bins a pressure release valve or other device is fitted to prevent excess pressures developing and distorting the bin walls. The ‘air’ that escapes consists of carbon dioxide and nitrogen. The further production of carbon dioxide can result in an atmosphere containing as much as 95 per cent of this gas.

It is not necessary to add nitrogen, carbon dioxide or other inert gas, as the micro-organisms themselves create the lethal atmosphere. The effects of adding inert gases have not been fully investigated at the time of writing.

**Effect on Germination**

One effect of removing the oxygen, coupled with the high moisture content, is to lower the germinative capacity of the grain. Generally, the grain remains unharmed for some time and then suddenly its viability falls to a very low level. Once again, the rate at which the reduction takes place varies with the moisture content and temperature. At 24 per cent moisture content deterioration begins in about 2 weeks; at lower moistures (below 20 per cent) viability may be maintained for several months, especially in cool weather.

**Effect on Milling and Baking Properties**

The taint noticeable in the unmilled grain is carried over to a lesser degree to the flour, and at moderately high moisture levels (above 20 per cent) is detectable in the bread produced from it.

Chemical changes involving the gluten, and changes in the amount of sugars in the grain, are sufficient to affect its milling and baking properties. There is deterioration in the quality of the dough, and in the volume, crumb structure and colour of the resultant loaves.

The effect of these changes is lost when the grain is mixed with a high proportion of normally stored wheat. Nevertheless, airtight storage cannot be recommended for grain intended for milling, unless the moisture content is so low that it could be safely stored by conventional methods.
AIRTIGHT STORAGE OF HIGH MOISTURE GRAIN

USE AS ANIMAL FEED

As far as is known, the changes that take place in high moisture grain during airtight storage are not harmful to livestock, and the grain can be used satisfactorily in a feed mix, both for beef and dairy cattle, and for sheep. The grain is readily accepted by the stock.

Further research is needed, however, on the chemical and nutritional changes that take place during the anaerobic (oxygen-free) phase of the storage, to determine what effect they have on the feed value of the grain.

PRACTICAL CONSIDERATIONS

It must be emphasized that, for hermetic storage to be completely successful, the bin must be truly airtight when closed. When erection is completed, the airtightness should be carefully checked by a suitable pressure test. As, during use, mechanical stresses may cause a certain amount of strain on the walls, it is desirable that periodic pressure checks are carried out, to make sure that the bin is still airtight. Manufacturers should be expected to provide facilities for these tests as part of their service.

Even a slight entry of air, either through a permanent leak or through a hatch left open for too long, will admit enough oxygen for moulds to grow. With only a slow leak of air, organisms such as mycelial yeasts, which can grow in very low concentrations of oxygen, will develop and give a mouldy appearance to the grain.

CONSTRUCTION OF THE BIN

For a stable oxygen-free system to be established, the bin should be of metal, of either a welded or a specially bolted construction, so that the joins are airtight. Particular attention should be paid to the sealing of the roof and covers to manholes or openings for insertion of filling or unloading devices.

Bins can be constructed of welded steel plates, painted or unpainted inside, of vitreous-enamelled ('glass-lined') plates or galvanized bolted steel plates. All are being used successfully for high moisture grain. If not otherwise treated, the steel of an airtight bin should be suitably painted externally to prevent rusting. At the time of writing it is not known what effect the damp grain has on galvanizing or on untreated steel or aluminium. The condition of the inside walls should therefore be examined each season for signs of rust damage or corrosion. This is most likely to occur at the top of the bin, where there may have been condensation on the wall above the grain level.

The need for an adequate pressure release valve, operating at a few inches of water pressure, or some other means of regulating pressure, such as a 'breather bag' (Fig. 28), has already been mentioned. These devices should be checked periodically to see that they are functioning properly. In cold weather low-pressure valves let in only an insignificant amount of air.

There is insufficient evidence at present to say whether bins of materials other than metal would be satisfactory for the storage of high moisture grain. Ordinary brick, wood or concrete bins are very porous to air. Treatment of the inside of the walls with substances such as bituminous or plastic paints or epoxy resins, or lining with sheets of polythene, polyvinylchloride (PVC) or
other plastic material have been suggested as means of making a bin airtight.
It is possible that they might be successful, if mechanical damage could be
prevented and if the moisture content of the grain were high (over 30 per
cent). Such grain (category iii, on p. 91) seems to undergo changes more akin
to silage than to truly hermetic grain.

![Diagram of breather bag](image)

Fig. 28. Use of breather bag to minimize gas exchange with atmosphere outside silo.

The success obtained with high moisture grain in certain non-airtight
treated concrete bins, in which the grain surface was covered with a plastic
sheet below the metal dome at the top, is probably due to the creation of an
'unstable' oxygen-free condition by grain of very high moisture content (over
30 per cent). It would be inadvisable to use such bins at moisture levels lower
than this. The effective low-oxygen atmosphere is only maintained by the
activity of micro-organisms (not necessarily in quantity enough to be visible)
in the uppermost layer of grain. This very high moisture grain is extremely
soft and compacts to form a firm crust, at least on the surface, which effectively
excludes air from the grain below. These bins are unloaded from the top, and
each successively exposed layer uses up most of the air getting in, while the
main mass of grain remains in a 'blanket' of carbon dioxide.

The principles of this type of storage are still largely a matter for con-
jecture, and any storage of high moisture grain in non-airtight bins must still
be regarded as experimental.

**Loading and Unloading**

Where practicable, a bin should be loaded as quickly as possible, and should
preferably be filled completely. It is important that the cover over the
aperture used for filling is replaced whenever loading is not in operation, i.e.,
onight or in longer periods of non-use, even if this means removing augers,
ducting or pneumatic loading devices. Any conventional conveyor or loader
is suitable for filling the bin. Care must be taken that any aperture used for
loading or unloading is closed adequately, such as by a metal plate bolted
against a rubber gasket.

In the first few weeks of storage there may be appreciable settling of the
rather soft grain, and further grain can be added later, if convenient. It is
preferable to leave the grain in the bin for a few weeks before using. This
allows oxygen-free conditions to be established, and also fits in with the practice on most farms.

Unloading from the bottom may present certain difficulties, particularly because of the bridging that may take place due to pressure between the relatively soft grains. Flexible augers and worm conveyors are the cheapest forms of unloading device, but are sometimes unable to deal with the bridging. They may also leave some grain which has to be removed by hand. A sweep auger unloader overcomes both these difficulties, but is more expensive.

**Frequency of Opening**

One of the most important problems confronting the user of an airtight bin is that of opening to remove grain. Unless some special air-lock device is provided, there is the risk of letting too much air into the bin. Some bins are fitted with unloading devices which operate without the bin being opened, but in many bins an auger has to be inserted through a temporary opening in the bin wall.

Provided rigid precautions are taken to keep the opening time to a minimum, grain can be removed daily or less frequently as required. If the opening is small and the cover only removed for a short time, most of the
carbon dioxide will remain in the bin and only a small amount of air will enter, the oxygen in which will soon be used up once airtight conditions are restored.

No more grain should be removed at one time than is required for two or three days' use, as, once exposed to the air, the high moisture grain will become mouldy in a few days. Mouldy grain is dangerous not only because of the irritation caused by the mould spores in the air, but also because certain moulds can produce toxic substances which could be harmful to the stock.

As a bin becomes nearly empty, a small quantity of grain may become mouldy, as the large air-space in the bin provides enough oxygen for moulds to grow. It is fortunate that the greatest use of airtight storage is during the winter and early spring, in cool weather, when growth of moulds is fairly slow. By the time the weather is warm enough for moulds to grow rapidly, most bins will be empty and the cattle out to grass.

Fig. 30. Arrangement of emptying tubes in air-tight high-moisture silo
AIRTIGHT STORAGE OF HIGH MOISTURE GRAIN

DANGER DUE TO LACK OF OXYGEN

Mention has already been made of the replacement of the oxygen in the air by carbon dioxide during airtight storage, thus creating a very dangerous atmosphere. The hazards of entering a bin filled with grain, or getting inside a nearly empty bin to remove the last of the grain, unless it has been adequately aired, cannot be over-emphasized. Carbon dioxide is an invisible gas which gives very little warning of its lethal effect. All known makers of these bins have agreed to fix a notice on the outside giving clear warning of the presence of carbon dioxide gas. Even when all precautions are taken, however, a worker should not be allowed to enter a bin without a companion being near, to get help in case of accident.

STORAGE IN PLASTIC CONTAINERS

When considering airtight storage the question will inevitably arise of the possibility of using plastic materials, such as polythene or PVC, either as independent containers or as liners for brick, concrete or non-airtight metal bins, or metal-mesh cages.

Storage in such materials can at the moment only be regarded as experimental, although success has been claimed by several users. For instance, high moisture grain has been kept by several farmers in polythene sacks. The storage period, however, has generally been limited to the winter months, when it was probably too cold for moulds to grow, and the success may have been due as much to the low temperature as to the effectiveness of the plastic, as other tests, in warm weather, have not been so successful.

Even assuming the plastic itself is sufficiently impermeable, there may be pinholes in it which would allow air to enter. Some plastics allow oxygen to pass in slowly although they are much more resistant to water vapour. Thus there would be no possibility of the grain drying out, but enough oxygen might enter to allow moulds to grow. Closure of the material can present difficulties, but new adhesives now coming on the market may make sealing easier. With bin linings it is difficult to prevent accidental damage to the fabric during insertion of the plastic or when loading the bin, and there is also the possibility of damage during storage and unloading. The question of the strength of the material must also be considered. Some of the plastics, 'supported' on a woven terylene or nylon material, may be strong enough to bear the weight of a certain amount of grain, but they are expensive.

Plastic liners to pits and plastic covers to stacks of bagged grain cannot be regarded as providing airtight storage, but they may have possible use as temporary covers for dry grain to be kept for a short period, say, at the site of harvest.

The main hazard to storage in plastic containers is damage by rodents, and until this has been overcome, storage in polythene sacks should only be considered when no other alternatives are available, or when the storage period is to be relatively short.
Air Heaters and Fans

AIR HEATERS

Fuels

As is explained elsewhere, the majority of farm grain driers make use of air as the drying medium. The air must be heated to a greater or lesser extent, according to the system of drying, etc., and for the sake of mechanical simplicity it is, where practicable, heated by fuels of which the products of combustion can be safely passed through the grain when mixed with air. Such fuels include diesel or gas oil, paraffin, coke, coal gas and propane or butane gas. The suitability of the above fuels for direct firing of driers depends on proper equipment being used. Where direct firing is not practicable, heat exchangers are employed. Electricity is also widely used for air heating, but as a rule only where relatively low temperature air is required, or for driers of low drying capacity.

When comparing costs, the effectiveness of fuels or electricity for air heating may be judged by their calorific value or heat equivalent, taking into account the efficiency of any heat exchanger, if used. Approximate calorific values are given in Table 14.

<table>
<thead>
<tr>
<th>Heat Source</th>
<th>Calorific value B.t.u.</th>
<th>Unit of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gross</td>
<td>net*</td>
</tr>
<tr>
<td>Diesel or gas oil</td>
<td>166,000</td>
<td>156,000</td>
</tr>
<tr>
<td>Coke</td>
<td>12,500</td>
<td>—</td>
</tr>
<tr>
<td>Coal gas</td>
<td>500†</td>
<td>450</td>
</tr>
<tr>
<td>Propane</td>
<td>21,500</td>
<td>19,600</td>
</tr>
<tr>
<td>Butane</td>
<td>21,300</td>
<td>19,600</td>
</tr>
<tr>
<td>Electricity</td>
<td>3,415</td>
<td>—</td>
</tr>
</tbody>
</table>

* Net values are less than gross values by the amount of heat that would be released if the water vapour formed in the course of combustion were to be condensed and cooled to 60°F. The net value for coke depends on its moisture content. It is customary to use gross calorific values when stating test results.

† On this basis 200 cu. ft = 1 therm = 100,000 B.t.u.

OIL-BURNING FURNACES

DIRECT-HEATING TYPE

A typical oil furnace of the direct-heating type comprises a cylindrical inner member made of stainless steel, or of mild steel lined with firebrick. This is fitted with a burner at one end and gas outlet ports at the other. The inner
membel" is surrounded by a steel casing, and cold air is drawn through the annular space between the cylinders, mixing with furnace gases before being passed into the fan. The burner produces a finely-atomized spray of oil, and simultaneously introduces a supply of primary air for combustion. A secondary supply of air is also introduced, either by the burner or through holes in the end cover, to prevent excessive temperatures in the furnace.

The primary air supply is produced by a small high-pressure fan or rotary blower, and the fuel is either supplied by a pump or sucked into the primary air stream on the carburettor principle. Safety devices, to prevent incorrect starting procedure, and to stop the flow of oil in case of flame failure, are invariably fitted. The rate of firing is controlled by throttling the fuel and primary air supply. Thermostatic control can be readily incorporated.

When correctly operated and maintained, the furnace should produce no smoke or soot, and cause negligible contamination. Diesel oil is the most commonly used fuel. The heavy grades of furnace oil are seldom used for grain drying as the total consumption does not warrant the additional expense of the necessary pre-heaters, etc.

**INDIRECT-HEATING Type**

It is sometimes desirable to heat the air indirectly by means of a heat exchanger, so that none of the furnace gases pass into the grain. This requirement may arise, for example, when an oil burner, running unattended for long periods, might damage a large quantity of grain through the occurrence of a mechanical fault leading to prolonged incomplete combustion of the fuel. Again, when a drier is to be used for other and more combustible materials than grain, the fire risk with direct heating might be considered excessive. In some countries, the use of heat exchangers is compulsory.

A heat exchanger is commonly in the form of a nest of tubes, through which clean air passes, while the furnace gases sweep the outer surface, or vice versa. The efficiency of such a heat exchanger is limited by considerations of first cost, and also by the necessity of avoiding gas outlet temperatures low enough to lead to partial condensation which would cause excessive corrosion of the structure.

**ELECTRICAL HEATERS**

Electrical heaters are usually in the form of a bank of low-temperature heating elements enclosed in a short length of ducting. When only low temperature air is required, this ducting may be fitted either on the inlet or the outlet side of the fan; otherwise it should be on the outlet side. The electrical supply to the heater should be interlocked with the fan-motor circuit to ensure that the heater cannot be run without the motor. For further safety an over-temperature cut-out thermostat is usually fitted. Thermostatic control can be provided to maintain a steady temperature regardless of variations in airflow, or simple hand-switching may be installed to give temperature variations in 1° steps or more as required.

In spite of the high cost of electricity as a means of heating, its use can often be justified on account of cleanliness, safety, ease of control and maintenance, or the low first cost of small fan-and-heater units. Its use is
generally limited to the smaller sizes of sack drier with loadings up to 21 kW (although units requiring up to 48 kW are available), ventilated bins, small tray dryers and the smallest sizes of continuous flow dryers. Larger dryers, used especially for seed, are sometimes heated electrically, but the electrical heating of a 1 ton per hour drier would usually entail special provision by the electrical authorities of cables, transformers, etc., and a high maximum demand charge might also be incurred.

Any proposed installation should be discussed in the early stages with the electrical authorities concerned, to settle not only technical problems, but also the question of the most favourable tariff.

**GAS BURNERS**

It is particularly important that gas burners should be properly designed, for although gas is a clean and convenient fuel, the risk of explosion calls for adequate precautions. For instance, accidental escape of unignited gas can be guarded against by a flame-out thermostatic cut-out; a gas cut-off valve can be fitted which will only allow gas to pass when the fan is running. An electric igniter for the pilot jet can be similarly interlocked. Compact, portable industrial heaters are available which are convenient for use in grain drying installations.

Owing to the widely differing air/gas mixture ratios for the various gaseous fuels, equipment designed for town gas is unsuitable for burning propane or butane gas and vice versa.

**COKE-BURNING FURNACES**

To avoid undesirable fluctuations of air temperature, it is important that the heat output of the furnace should remain constant with the minimum of attention. Simple hand-fired furnaces are not, therefore, suitable owing to the close supervision required to produce even a roughly steady temperature. However, a number of coke furnaces of the gravity-feed types are available and if correctly operated will give a very reliable performance. There are two main types of such furnaces, the simple gravity-feed type and the semi-producer furnace.

**FANS**

A knowledge of the basic properties of fans will assist in selecting suitable machines and operating them.

**Centrifugal Fans**

There are three main types of centrifugal fans. The simplest is the paddle-blade which has six or more flat blades set radially to the fan shaft. They are used where low cost is particularly important or where solid particles have to pass through the fan, as in some grain cleaners.

Fans with forward-curved blades are commonly used for low pressure, high volume applications. They are usually made with a large number of closely spaced, shallow blades and deliver more air than a paddle-bladed fan
of the same dimensions and speed. They are commonly used in continuous flow grain driers and other applications where they can operate against a fairly constant pressure.

Fans with backward-curved blades are used where there is considerable variation in the required duty and the power consumed must be kept within definite limits. The blades are fewer and more robust than those of forward-curved blade fans and for a given size and duty, the shaft speed must be much higher. Because of their non-overloading characteristic they are often used in bulk grain driers.

**Axial Flow and Propeller Fans**

In these fans the flow of air past the impeller is in the general direction parallel with the axis of the fan shaft. In this country the name ‘propeller fan’ generally implies a relatively slow speed fan with broad plate-type blades in a simple ring mounting, whereas the term ‘axial flow’ is used to describe fans having impellers with multiple aerofoil-shaped blades working with small clearance in a cylindrical duct. Propeller fans are essentially low pressure fans whereas the axial flow type can produce much higher pressure, particularly if used in pairs rotating in opposite directions. They have a non-overloading characteristic. Most axial-flow fans are directly motor driven and their motors rely on the airstream generated by the fan for cooling. Care must therefore be taken not to increase the resistance against which these fans operate to such an extent that insufficient air is passing to cool the motors, nor to exceed the safe working air temperature for them. They are used both for continuous flow grain driers, hay and bulk grain driers and have other applications. Propeller fans are mainly used for ventilating buildings.

**Fan Performance at Constant Speed**

Fan characteristics, that is the relationship between the pressure, volume, speed, and power consumption, are listed in manufacturers' catalogues and can conveniently be expressed graphically. Such characteristics are shown in Fig. 31, for two imaginary machines running at constant speed. It has been assumed here that a fan is required to deliver 5,000 c.f.m. against a pressure of 3 in. w.g. The performance characteristics of two imaginary fans capable of this duty, one a double-stage axial flow fan and the other a straight-bladed centrifugal fan, have been drawn. Two pairs of curves are shown; at the top the pressure-volume curves and at the bottom the horsepower curves. Each fan delivers the same volume (5,000 c.f.m.) at the required pressure (3 in. w.g.), and takes the same power (4.75 h.p.). If, however, the pressure were to fall to, say, 2 in. w.g., the volume delivered by the centrifugal fan would rise to 6,100 c.f.m. and the power consumption to 5.6 h.p. The delivery from the axial flow fan would increase to only 5,400 c.f.m. and the power consumption would fall to 4.3 h.p.

These examples illustrate several important features. For all centrifugal fans running at constant speed, except backward-curved blade fans designed to have non-overloading characteristics, an increase in volume of air delivered causes an increase in power consumption. Blank ing off a fan inlet or delivery therefore reduces the power consumption and, conversely, running a fan
against zero pressure may overload its power unit unless it has been designed to include this duty. This is particularly important with forward-curved bladed fans, which are usually avoided by designers in applications where widely-fluctuating pressures are encountered (e.g., for ventilated bins).

**Speed Variation**

If the characteristics of a fan at a given speed are known and it is desired to estimate its performance at a different speed, characteristic curves for the new speed may be plotted based on the original data by means of the following rules:

- volume varies directly with the fan speed;
- pressure varies as the square of the speed;
- power requirement varies as the cube of the speed.
For example, if the fans in Fig. 31 were running at 1,500 r.p.m. and their speeds were to be raised to 2,000 r.p.m. the particular point on the top curve, 5,000 c.f.m. at 3 in. w.g., would move as follows:

New volume = \( 5,000 \times \frac{2,000}{1,500} = 6,666 \text{ c.f.m.} \)

New pressure = \( 3 \times \frac{2,000^2}{1,500^2} = 5.35 \text{ in. w.g.} \)

For the corresponding power value:

New power = \( 4.7 \times \frac{2,000^3}{1,500^3} = 11.1 \text{ h.p.} \)

Other points may be calculated similarly to enable required portions of the curves to be redrawn. It is particularly important to observe the very marked increase in power consumption at the higher speed. The power required for a given speed of operation is affected by the density of the air being handled, which depends on its temperature and the barometric pressure.

![Air volume C.F.M. x 1000](image_url)

Fig. 32. Variation of fan performance with number of silos ventilated

**Estimation of the Operating Point of a Fan**

It is clear, from the slope of typical fan characteristic curves, that a change in the resistance to airflow in the drier or other systems in which the fan is used will usually change the rate of air delivery. A complicated problem arises when a fan is to be used under widely varying conditions as in a ventilated bin installation.
The procedure in such a case is to plot resistance curves for each bin or combination of bins, which are to be ventilated at one time, when filled with the appropriate type of grain, the resistance including that due to the air ducts etc. An example of a set of such curves is given in Fig. 32. System resistance curves are given for from 1 to 8 silos, each of 100 sq. ft floor area, loaded with wheat to a depth of 10 ft, together with a curve for 2 similar silos loaded 5 ft deep. The characteristics of two dissimilar fans (broken lines) superimposed, enable the operating points of these fans, under the different conditions, to be read off at the points of intersection with the resistance curves. Fan A might be employed where not more than 3 silos are required to be ventilated together or where power is strictly limited. Fan B might be chosen where more power is available and a more uniform rate of ventilation is desired. Resistances of various types of grain and seeds to airflow are given on p. 26. By means of these, with due allowance for duct and other resistances, similar sets of system resistance curves may be constructed to suit individual requirements. Data for calculation of resistance of duct systems are available in the literature of fan engineering.
Conveying Equipment

The conveying system is a vital part of any storage plant and should receive as careful consideration in its selection and installation as the drier or cleaner. Several types of conveyor are available, each serving a different purpose: by using a combination of the various types most conveying problems can be solved without undue complication. The actual simplicity or complexity of the system will depend, of course, on such factors as the total tonnage of grain to be handled and stored, the maximum rate of throughput required, the method of drying used (i.e., continuous or batch), whether a pre-cleaner and dresser are used, and so on.

Certain general points should be borne in mind when planning a conveying system, namely:

- the need to avoid any bottlenecks;
- the need to have more than adequate capacity under all foreseeable operating conditions;
- the need to make allowances for future development so that additions to the system can be made with a minimum of alteration. (For example it might be sensible, if bulk handling ex-farm is envisaged at some future date, to install a twin-leg bucket elevator with only one leg in operation temporarily, the twin unit being available, however, when the higher capacity demanded by bulk handling is required);
- the need to make the best possible use of the height available in the storage building, i.e., the overhead horizontal conveyors should be mounted as high as possible so that maximum distribution can be obtained with a simple gravity system.

BUCKET ELEVATORS

The bucket-type elevator is in common use where vertical or almost vertical conveying is required. Mild steel pressed buckets up to 12 in. wide are attached at approximately 9 to 12 in. centres to an endless belt which is usually driven from the top by a large diameter pulley: belt tension can be altered by adjusting a similar idler pulley at the bottom. The belt is enclosed in rectangular trunking, commonly made of wood, to which are attached the discharge (head) and inlet (boot) assemblies. Most elevators are designed as single units, but they can be obtained as twin units with a common driving system. In this way either two different materials can be conveyed simultaneously, or both units can be used to give double the output of the single unit.

Belt speeds depend on the size of the head pulley and must be such that discharge from the buckets is as clean as possible; values up to 250 to 300 ft/min are used. Throughputs up to 30 tons per hour for a single unit are possible, and elevating heights up to 45 ft can be arranged. The power requirements vary with capacity, height and efficiency of the conveyor, but a typical figure for a 10 in. wide bucket, elevating 18-20 tons per hour over a height of 40 ft, is 3½ h.p. Sufficient power should be available to allow the elevator to be started with a boot full of grain.

Normally grain is fed into the elevator on the 'up' leg, but it is possible to do so on the 'down' leg, with a consequent reduction in throughput and
increase in power consumption. Access doors in the boot are necessary for cleaning-out, which should be done between runs with different materials or whenever the elevator is likely to stand idle for some time: an inspection panel is often provided at eye-level in the up leg. Although the belt speed may be at or near the optimum value, there will frequently be a tendency for some grain to be discharged into the down leg, and a cut-off plate is sometimes fitted to blank off the gap between the buckets and the trunking.

Fig. 33 shows a typical installation in a grain intake pit. The elevator trench is about 2 ft lower than the pit discharge which is fitted with a quick-release slide. Adequate space is allowed for access to both sides of the boot, which is raised on rails 2 in. above floor level. The discharge chute is about 2 ft below the head of the elevator. A frame mounted on the trunking carries the motor and lay shaft, and a simple means of tensioning the belts is provided. The trunking is vertical and the bottom idler pulley is adjusted to the minimum tension required to prevent the belt slapping the casing.

![Fig. 33. Bucket elevator installation](image-url)

All types of grain and seeds can be handled virtually without damage, and the relatively high mechanical efficiency, low cost, reliability and ease of maintenance make the bucket elevator entirely suitable for farm use in fixed installations.

Because of their high rates of throughput, bucket elevators with suitable
outlet ducting and particularly twin units are ideal for the direct loading of grain tankers, where bulk handling from the farm is used, and where no drive-under hopper is feasible.

AUGER CONVEYORS

Auger, or screw, conveyors are now used extensively for handling a wide range of materials; many farm machines incorporate them (e.g., bulk-handling trailers and combine harvesters), and they are available either as fixed or mobile units for conveying grain. When used as fixed, horizontal or slightly inclined conveyors, they consist of an auger screw running at slow speed in a U-shaped trough. If the screw is enclosed in a cylindrical casing, and run at a much higher speed, the conveyor can be used at any angle between horizontal and vertical. In nearly all cases the auger screw is now made in continuous lengths by a cold-rolling process, and for general purpose conveyors the pitch and diameter are approximately equal. Throughput depends primarily on the diameter of the screw, its speed of rotation, and on the angle of elevation of the conveyor.

The totally enclosed high-speed augers are usually designed as mobile conveyors (Plate V, upper) or in the case of the smaller models as portable units, but are occasionally incorporated in a conveying system as fixed units. Diameters vary from 3 to 9 in., and the smaller augers run at speeds up to 1,200 r.p.m. The smaller models can be obtained in lengths of up to approximately 30 ft, and the larger models up to 40 ft or more. Augers are usually made in such a way that there is a basic unit to which extensions can be added as required. With the smallest size the throughput, when conveying wheat at an angle of 45 deg., is approximately 6–8 tons/hour, and a comparable figure for a large diameter size (9 in. dia.) is 50 to 60 tons/hour. The power requirements range from 1½ h.p. for a small auger 30 ft long, to 10 h.p. for a large auger 35 ft long. However, wet grain can reduce auger output by up to 50 per cent, and where high output is essential, this fact should be borne in mind. Most conveyors are fitted with an adjustable intake slide so that throughput, and consequently the power required, can be adjusted to avoid overloading the motor under particularly adverse conditions. Intake arrangements vary with the particular application: they can be used with a hopper attached to the inlet, with the inlet in a pit, or inserted directly into a bulk of grain. It is a statutory requirement that all farm machinery should be adequately guarded, but augers, in particular, require suitable protection at the inlet (Plate V, lower left) fingers are lost each year because of a lack of such protection. At steep angles augers are self-cleaning, except at the inlet, and provision should be made for cleaning the intake hopper or pit. Most augers do some damage to the grain, especially if the conveyor is running partly full; but for one or two passes only through an auger the amount of damage can be regarded as negligible.

The diameter of a slow-speed trough conveyor will normally be between 5 and 10 in., and its speed from 100 to 200 r.p.m.; throughputs of up to 30 tons per hour are possible. In order to avoid grain damage, there is a clearance of greater than one grain thickness between the casing and the screw, and it follows that the conveyor is not self-cleaning. Brushing out is
difficult but the trough can be made with removable or hinged sides. Grain can be fed into or discharged from the conveyor at any point along its length. It is reliable in operation, does not block easily, and is particularly suitable for runs of short or moderate lengths, where one main type of grain is involved.

**Sweep Augers and Collectors**

Two recent innovations making use of augers, are worthy of note, one being designed to overcome the problem of emptying a silo which has no self-emptying base; the other to make the job of clearing grain from a floor-drying and storage unit easier. In the first case a motor-driven open auger is mounted on a spigot in the base of a silo and is free to rotate both vertically and horizontally about the spigot (Fig. 34). When running, the auger rotates around the silo conveying grain to a central outlet which feeds another conveyor; if it is suitably balanced it will follow the level of the grain as the bin is emptied.

![Fig. 34. Sweep arm auger driven by separate motor](image)

With the large-scale introduction of floor-drying and storage, the problem of removing the grain after storage has led to the development of 'collectors' which are attached to the inlet of carriage-mounted auger conveyors. The collector, which is mounted at right angles to the axis of the conveyor, consists simply of two short lengths of opposite-handed auger screw mounted on a common shaft which is driven by a separate motor. The frame of the collector is mounted on wheels, and as the unit is pushed into a heap of grain, the collector augers convey grain to the middle of the collector and into the conveyor inlet. (Plate V, lower right)
Belt Conveyors

Belt conveyors are used almost exclusively for horizontal conveying, but slight inclines up to 15 deg. are permissible; above this angle and up to approximately 30 deg., ribbed belting is necessary and the throughput is reduced. Conveyors with either flat or troughed belts are available. Belt widths up to 12 in. are commonly used with belt speeds up to 250 f.p.m. Throughput, which depends on belt width and speed, can reach a maximum of approximately 30–35 tons per hour with a 12 in. troughed belt; the power requirement for such a conveyor is approximately 1 ½ to 2 h.p. per 50 ft length.

With either a flat or troughed belt the method of feeding the grain on to the belt is important, since a poor system will result in grain bouncing or running over the edge of the belt; normally the grain is 'moulded' into a central heap by guide vanes. Grain can conveniently be fed on to the conveyor at any position along its length, and the discharge may be either from the end of the belt or anywhere along its length, by making use of an inclined scraper or an off-loader of the type shown in Fig. 35. With a reversing motor, a belt conveyor can be designed for use in either direction.

Belts normally stretch with use and ample provision for adjusting belt tension is necessary; changes in belt length due to variations in weather conditions are less likely with the increasing use of plastic covered belting.

Belt conveyors are ideal for systems where high throughputs and moderate lengths are involved, particularly where a single discharge is required. No damage to grain is caused by this type of conveyor, and they are entirely self-cleaning and raise comparatively little dust.
Chain and Flight Conveyors

(Plate VI, upper)

This type of conveyor is normally used for horizontal conveying or up very slight inclines. It consists of a chain with transverse flights of varying shape, spaced at intervals of 6 to 12 in. approximately; the chain runs in an open wooden or metal trough, which can be either rectangular or semi-circular in cross-section, and the grain is dragged along the trough by the flights. If the chain is totally enclosed and special flights are used, this type of conveyor will operate at any angle up to vertical, but such an application is not common on farms. In both systems the working section is almost completely filled with grain. Chain and flight conveyors will work equally well in either direction if some means of reversing is provided.

Flight widths of up to 12 in. are used, and chain speeds can vary between 20 and 150 ft per min., depending on the type of flight used. Throughputs up to 20 tons per hour are common and conveying lengths can extend up to 100 ft. Power requirements will depend on throughput, type of material and conveying length, but a typical example is 1 h.p. for a 15 ton per hour conveyor 70 ft long.

Grain can be fed on to the conveyor at any position along its length, either from above or through the side, and multiple outlets can be arranged.

The open trough type of chain and flight conveyor is ideally suited to installation between rows of storage bins, mounted either above the bins or in a trench below the bin outlets.

Oscillating Conveyors

Low frequency oscillating conveyors can be used to convey grain horizontally or slightly up-hill. A light trough is supported on springs or links about 6 to 12 in. long spaced at approximately 6 ft intervals. The trough, which can be up to 12 × 6 in. in section and 60 ft or more in length, is coupled to a crank or eccentric having a throw between 1/2 and 3 in.; it is set so that the trough is lifted on the forward stroke. Frequency of oscillation depends on the size of conveyor, crank throw and required throughput, and a conveyor with a trough 8 × 3 in. deep handling 8 tons per hour would run at 200 to 400 r.p.m. Such a conveyor would require a 1 h.p. motor for lengths up to approximately 50 ft.

Grain can be fed on to the trough at any position along its length and multiple outlets can be arranged. The conveyors are self-cleaning to a high degree and cause virtually no damage to grain.

Although vibration can be minimized by balancing, this type of machine is suitable only where a firm mounting can be provided.

Pneumatic Conveyors

At air speeds between about 60 and 75 ft per sec, cereal grains can be blown along a pipe either horizontally or vertically without risk of blockage or excessive damage. The pressure required is high, and the volume of air needed must be provided by a high speed 'blower' type of centrifugal fan. The size of pipe needed is determined by the maximum throughput and pipe length.
required, and may be about 6\(\frac{1}{2}\) in. diameter for about 4 tons per hour, 9 in. diameter for about 6 tons per hour and 12 in. for 8 tons per hour. Though pressure-type conveyors are normally used, the conveyor pipe may be attached to the suction side of the fan, in which case the grain is very readily introduced through openings at any point or points. The grain is extracted by a cyclone before it reaches the fan. With a pressure system the grain must be injected either by venturis (see Fig. 36)—which, by locally speeding up the air, lower the pressure to that of the atmosphere and prevent 'blow-back'—or by mechanical rotary feeders. The grain is extracted at any point through outlet cones or separating chambers such as cyclones. The advantages of the pneumatic system are its flexibility, self-cleaning action, and its ability to convey long distances. The disadvantages are high power consumption, noise, and dustiness. For very long runs the power consumption rises steeply and the capacity falls off. Pneumatic conveyors cause little damage to grain during a single pass, provided that the air speed is not excessive, but after repeated passes damage may become noticeable. Portable units are available and are particularly suitable for small and simple storage plants.

![Fig. 36. Pneumatic conveyor injectors](image)

In planning the layout for a pneumatic conveyor, bends, vertical lifts, and the number of inlet and outlet points should be minimized to reduce costs and ensure a high throughput.

Maintenance is very simple, and the only major wearing parts are the bends, which may require replacement after a few season's running.

It is not generally desirable, except perhaps for very small ventilated silo plants, to use the conveyor fan for other duties because its high-pressure, low-volume characteristics are normally unsuitable.

**Miscellaneous**

Two novel methods of moving grain have recently been introduced. The first, namely the grain 'thrower', is another device developed to facilitate the practice of floor-drying and storage. It consists, simply, of a mechanical
means of projecting the grain, for example, by using a high-speed rotating paddle with rubber tips to the blades: outputs of up to 40 tons per hour over distances of 60 ft are claimed.

The second device provides a pneumatic means of removing the last few tons of grain from a particular type of radially ventilated bin or a floor-ventilated bin which has no self-emptying hopper bottom. A false floor of expanded metal is fitted into the bin in such a way that air blown through the shaped openings in the metal is directed towards the bin outlet carrying grain with it. In the case of radially ventilated bins, the standard ventilation ducting is modified, so that air can either be used for drying or blown through the floor for emptying.
Cleaning Equipment

Not only the market value, but also the keeping quality of grain is improved by cleaning, and it is these benefits which make the installation of some type of cleaning machinery an economic proposition on almost all farms. A clearer picture of the situation is obtained by considering separately the three major groups into which farm cleaning operations fall. These are:

Pre-cleaning i.e., cleaning the grain in such a way that the subsequent operations of conveying, drying and storage are facilitated.

Cleaning of Commercial Samples i.e., cleaning to an extent which will give the maximum economical increases in value without necessarily reaching seed standards.

Cleaning of Seed Samples i.e., cleaning and grading to an extent which will ensure that a potential seed sample is not rejected or lowered in value because of impurities or non-uniformity.

PRE-CLEANING

The presence of foreign matter in a sample lowers the efficiency of drying, and increases the hazards of storage. The following advantages of pre-cleaning can be expected to accrue to an extent depending on the completeness of the operation:

- foreign matter, which is liable to restrict the airflow through, and to clog the air passages in a drier, is removed. Relatively impervious patches in a ventilated silo are similarly avoided. These tend to occur where the stream of grain and rubbish falls from the filling conveyor or spout;
- straws and large bodies liable to block conveying machinery are removed as soon as possible in the circuit;
- local spots of high moisture content caused by damp green matter are eliminated;
- final cleaning or grading before sale can be more rapid and accurate because of the reduced quantity of contaminants to be removed;
- the nuisance from dust is reduced—provided that the machine used has adequate arrangements for dust disposal;
- removal of dust and broken grains may reduce risk of insect infestation since insects feed more readily on such material than on undamaged grains.

From the consideration of these points it is apparent that the material to be removed by pre-cleaning falls into three groups:

- **Large**: Large straws, thistle heads, etc.
- **Small**: Sand and small weed seeds, etc.
- **Light**: Dust, chaff, short straws, leaves, shrivelled grain, etc.

These substances have very different characteristics from the parent sample and are not, therefore, particularly difficult to remove. The light fractions are likely to constitute the greatest weight of trash in a combine sample, and can best be extracted by aspiration. This method rests on the fact that bodies falling in air acquire a final constant or terminal velocity. The magnitude of this velocity depends upon the relation between the weight and aerodynamic resistance of the body, and obviously varies widely between the extremes represented by sound grain and dust. The effectiveness of
an aspirator depends upon its ability to maintain a uniform airflow at a velocity just less than that required to lift sound grain, and all factors affecting the air flow should therefore be accurately controlled.

Fig 37A depicts a machine with an aspirating leg or chamber of rectangular cross-section into which the material to be cleaned is fed, in a thin even stream, by a fluted roller. A shaking type would be an alternative feed mechanism. The feed mechanism of a precleaner must be able to deal with grain and straw mixtures without blocking. Fig. 37B shows an aspirator where, in effect, the rectangular leg of the first machine has been wrapped round into a circular shape. This produces a compact high capacity cleaner. The freely revolving cone below the feed chute distributes the grain in the air stream.

Fig. 37. Simple aspirators

Fine control of the air flow in a cleaner is important and, in practice, airflow is usually adjusted, so that a few good grains are removed with the rubbish. In this way, the maximum amount of light trash is removed from the parent sample and retained for feeding. The air flow may be produced by pressure or suction: both are equally effective. The suction system has the advantage of cleaner operation, as leaks in the machine do not give rise to dusty surroundings. Also the light rubbish may more easily be blown to the outside of the building, where it can be collected in a settling chamber or by means of a cyclone.

If the quantity of remaining contaminants, small heavy weed seeds, and long or knotted straw, etc., justifies the process, they can be removed by screening. A two-screen pre-cleaner will usually need to be provided with a range of at least five sieves with perforations ranging from \( \frac{3}{32} \) in. to \( \frac{1}{4} \) in. (see Fig. 38).

One type of stationary cylindrical screen, often fitted to combines, is not liable to blockage because of internal rotating paddles, which both feed grain along the screen and force hesitant grain through the holes. Such screens usually contain two sets of holes, the first for small weed seeds and the second
CLEANING EQUIPMENT

for good grain, while straws, heads, etc., are ejected over the end. Their capacity is normally rather low, being matched to combining rate.

An auger operating in a suitable perforated tube acts as a single screen cleaner sieving out particles smaller than the grain. Running in an inclined position this can feed the grain to an aspirator built on to the upper end.

Fig. 38. Two-screen cleaner with head aspirator

CLEANING OF COMMERCIAL SAMPLES

The operation of cleaning commercial samples carries the simple pre-cleaning process a stage further by reducing the quantity of contaminants, and by removing the obviously undersized grains.

The level of cleaning does not necessarily demand any technique other than aspiration and screening, the difference from pre-cleaning being essentially one of degree. A well-designed pre-cleaner, when used a second time after storage, will often be able to make an acceptable sample, if run at a low output with perhaps slightly increased air-blast, and a top screen with smaller and bottom screen with slightly larger perforations to make a closer separation.

A full-sized commercial-grade cleaner will often be fitted with a third screen to assist in the separation of small seeds, and possibly with a second aspirator (see Fig. 39). This aspirator may be located after the screens in order to treat only the good grain, in this way removing light stuff missed by the earlier operations, and dust produced during screening. A good machine is able to tackle many varieties of seeds other than the common cereals.
It can be seen that the primary distinction between a pre-cleaner and a commercial-grade cleaner lies in the purpose to which the machine is put, and not in any essential difference in the mechanism. A soundly designed pre-cleaner, used twice, will generally produce commercial samples, and a good commercial-grade cleaner may be used, at throughputs above those corresponding to maximum efficiency, to provide excellent pre-cleaning, so long as it will feed damp and dirty material.

CLEANING AND GRADING FOR SEED

The requirements of purity and uniformity for seed samples normally demand a more exacting process than the roughing-out which is often adequate for commercial samples.

Weed seeds having very similar dimensions to the parent sample, slightly undersized grains, and half-corncs have to be removed. While a variety of methods, all based on some difference in physical characteristics, are available to seedsmen who can justify the purchase of the equipment, farm seed cleaning operations are usually restricted to three methods:

controlled aspiration;
separation by width on screens;
separation by length on indented cylinders.

The process may start with a rough cleaning on a single screen to scalp off large impurities, followed by at least one, and sometimes two, controlled aspirations: the previous remarks in this connection apply. An enclosed leg with uniform grain feed and air blast must be used. If two legs are used, the
CLEANING EQUIPMENT

maximum blast to blow out just a few good grains should be maintained in each, the object being to have two opportunities of removing 'borderline' impurities and not merely to blow out the dust in the first leg, since it would in any case be removed in the second. Apart from the light trash, the aspiration will remove a considerable quantity of undersized grain and thereby facilitate following operations.

After aspiration the grain is passed on to a top screen. This will often be of circular hole pattern intended to remove long objects able to ride over the holes. If the impurities are not mainly long ones, then slotted holes are preferable to hold up all objects just larger than the seed. A second screen is chosen to hold up the greatest quantity of best seed that is economically justifiable—neither too large and hence uneven, nor too small to be profitable. The tailings from this operation contain a valuable quantity of feed corn and are therefore screened a third time on a fine screen to remove small weed seeds. A fourth screen may sometimes be desirable to enable the best of the tail corn to be bagged off separately, and all the screens must be automatically brushed or tapped to prevent blockage.

The efficiency and rate of working of the screens is controlled by adjustment of their slope, and sometimes the magnitude and speed of oscillation. The object is to maintain a full, evenly-fed screen without risk of overflowing and excessive bouncing. The good seed will thus, in general, contain only materials having a similar width and density—for example, cleavers and half-corns in barley. These can be extracted at a low rate of working on an indented cylinder. The grain is fed into the slowly rotating cylinder, and is carried up by the internal indentations until it overbalances and falls out. The point at which over-balancing occurs is clearly lower down for long seeds (barley) than for short (half-corns and cleavers), and the impurities can therefore be caught separately in an adjustable trough from which they are extracted by an auger. The cylinder may have two chutes and two sizes of indents to suit different materials. The good seed passes through the cylinder and is finally bagged.

In the event of the impurity being longer than the good seed the bagging-off positions are simply interchanged.

It is apparent that a seed-cleaning machine is necessarily complex, relatively expensive, and requires time, skill and close attention for its successful operation.

INSTALLATION OF CLEANERS

In a storage plant a cleaner inevitably requires an elevator to feed it, and as a vertical lift is generally required, a bucket elevator is the normal choice.

Except perhaps for very rough pre-cleaning, it is important that the elevator shall feed at a greater rate than the cleaner requires, and that the overflow is returned to its original source, say the wet-grain pit. Only in this way can the feed mechanism in the cleaner be kept fully covered, and even aspiration and screening ensured. The intake to the elevator should be fitted with a quick-release gate to enable straw blockages to be cleared without loss of the exact setting. If this is not done, constant alterations are required with dirty crops, to maintain a reasonably small overflow without risk of starving the cleaner. The chutes from the elevator should be run at steep angles, certainly not less than 45 deg., as dirty material will be handled. This applies
particularly to the overflow, which may tend to collect a disproportionate amount of straw, and which does not generally benefit from the elevator's dynamic discharge.

Most cleaners need to be mounted on a raised platform, which should be generously proportioned in strength and area to allow for vibration, and to give adequate access. Space is needed all round the machine for adjustment, maintenance, removal of screens, and storage of screens not in use. A clear area is required to lay out the screens for a trial with a handful of grain in order to make the best initial choice. If part or all of the cleaner discharges are above the floor level, then adequate sack storage and wheeling space is required.

It is probably better to bag off below the cleaner where this is feasible, so that the maximum space and convenience are provided. Trash chutes should have angles of at least 55-60 deg., if possible.

All air discharges should be fitted with ducts leading out of the building and should terminate in collecting chambers or cyclones. Manufacturers' recommendations should be followed in this connection, as there is a risk of over-throttling the fans and preventing adequate aspiration. The ducts should have smooth internal surfaces and run downhill where possible, to avoid accumulation of heavy grains.

Good lighting and ample ventilation should be provided.

OPERATION OF CLEANERS

The details of operation are so bound up with the machine and the crop being handled, that only very general points can be mentioned. The following notes may assist a new user:

Setting Up

The machine must be run at the maker's stated speed, and be accurately levelled.

Grain goes over and not under the feed roller, which should never 'grind'. The fan runs in such a direction that air flung off the blades goes through the outlet at a tangent without having to turn through a right angle.

Bolts should be tightened and screen hangers checked.

Cleaning brushes should be set to rub firmly and evenly.

The hopper, aspirator chambers, elevators and augers should be cleaned out.

Adjustable screens should not be closed without first opening out and cleaning.

Running

Grain should be hand-sieved in order to select best sizes of screens.

Aspirator should be set to blow out a few good grains.

If the fan is double-sided both shutters should be equally adjusted.

General correctness of screen sizes should be checked. If large grains apparently come through a small screen, check for leakages, possibly due to overloading.

Throughput should be increased until top screen is covered with grain for not more than half its length.
All screens should be checked for uneven feed, bouncing, and overflowing. Adjust pitch and tappers.

The best possible sample should be obtained on the screens before introducing the indented cylinder.

If the light rubbish is blown into a settling chamber or cyclone, the air outlet from this must be kept free from obstruction and blockage.
Measuring Instruments used in Grain Drying and Storage Plants

There is little point in building a well-planned grain storage installation unless adequate instrumentation is also provided to ensure the efficient running of the unit. It is necessary, for example, to measure with reasonable accuracy the moisture content of grain going into and coming out of the drier: a knowledge of certain other factors is also desirable, including ambient air temperature and relative humidity, drying air temperature, and possibly grain temperature during storage. Most driers incorporate some degree of automatic control, though this frequently consists simply of a thermostat operating an on/off control for the heater unit, so that the drying air temperature remains approximately constant: more sophisticated systems for regulating the output moisture content of the grain are being developed. It is important to remember that all the instruments used, either for measurement or control, are delicate and they should be treated with care; they should be properly maintained and regularly calibrated.

The cost of the instrumentation necessary for the sensible operation of the storage unit will be small compared with the total cost of the equipment.

Measuring Relative Humidity

All atmospheric air contains water vapour. Air at a particular temperature cannot contain more than a certain amount of water vapour. The relative humidity of air, at a given temperature, is very nearly equal to the actual weight of water vapour per unit volume of air, divided by the weight per unit volume when the air is saturated at that temperature and expressed as a percentage.

Relative humidity can be measured in various ways, none of those in common use being fundamental methods. The instruments most frequently used are the hair hygrometer, with variants using other organic materials in place of hair, and the wet and dry bulb hygrometer.

Hair Hygrometer

Hair hygrometers, and similar types which may use cotton fibres, silk threads, gold-heater's skin, etc., depend for their operation on the alteration in length of the fibre used with variation of the relative humidity of the air. The bunch of fibres is held in light tension and caused to operate a pointer by a suitable mechanism. The calibration of hair hygrometers is not noticeably affected by changes in temperature over the normal atmosphere range, but they are liable to permanent damage by temperatures above 150°F.

Hair hygrometers suffer from various limitations. They are subject to a time-lag while the hair is coming into equilibrium with the surrounding atmosphere, and they cannot therefore be used reliably in rapidly-varying conditions. They give different readings at a given value of relative humidity when the relative humidity has risen to that value and when it has decreased.
MEASURING INSTRUMENTS USED

The simplest form of the wet-and-dry-bulb hygrometer consists of two mercury-in-glass thermometers, the bulb of one of which is surrounded by a moist wick. Evaporation of the water from the wick into an unsaturated atmosphere lowers the reading of the wet-bulb thermometer and from the readings of the two thermometers the relative humidity of the air can be found by reference to standard tables, the figures in which are based on comparison with more fundamental methods of measurement. This type of hygrometer may be used in more or less still air or in fast-moving air, and two sets of tables are available, often headed ‘Screen’ and ‘Sling’ respectively. Use in fast-moving air (above about 13 ft per sec velocity) gives the more reliable results. A sling or whirling hygrometer is one arranged to give this fast-moving effect by having its pair of thermometers mounted together in a frame attached freely to a handle so that it can be whirled through the air. When it is being used in still air, the user should move forward while whirling it to prevent it being influenced by moisture evaporated from its own wet bulb and from his body.

Errors may be introduced into the results from a wet-and-dry-bulb...
hygrometer in several ways. It is essential that the thermometers should be matched to give similar readings over their range, and this matching is, within limits, more important than the absolute accuracy of the readings. For example, if the thermometers have a 1°F difference, one of them being correct, an error of 3 percent r.h. can arise at an average dry-bulb temperature and relative humidity, whereas if both thermometers agree but are in error by 1°F, the error in the same conditions is only about 0.5 percent r.h. The wick round the wet bulb should be a close fit, clean, and capable of maintaining the bulb in a wet condition. Failure in any of these points will lead to a reduced wet-bulb depression. The water-supply to the wick must be adequate and clean and should not be too far different in temperature from that of the wet bulb.

MEASURING AIR PRESSURE AND FLOW

The measurement of pressure and air velocity in drying plants can sometimes give a useful lead to correcting mistakes in construction or operation. For example, repeated measurements of the pressure drop through the porous floor of a ventilated silo can show whether the pores are becoming blocked, and the change of pressure along an air duct carrying air can show whether the duct is of adequate size for the air flow concerned.

Air pressures encountered in drying plants are usually quoted in inches of water, that is, the height of water column which can be supported by the air pressure or, as normally measured, the difference in height between the two columns of water in a U-tube or inclined-tube manometer, one leg of which is open to atmosphere and the other connected to the air supply. Such a pressure is, of course, the pressure of the air above atmospheric pressure. Normally an inclined-tube manometer is used where accurate readings of low pressure are required, up to, say, 3 in. w.g.; above this pressure and where a high degree of accuracy is not wanted, a U-tube can be used.

USE OF MANOMETER

Stationary air has only one component of pressure, known as static pressure, but moving air has, in addition, a component due to its velocity. If an open-ended tube is connected to a manometer and is pointed towards an air stream the total of the velocity and static pressures is measured; if it is at right angles to the air stream, only the static pressure is indicated, since the impact of the moving air on the tube opening is avoided. Usually a farmer or an advisory officer is interested only in static pressure measurements. Static pressure measurements in ducts are carried out simply by making a connection from a small hole in the side of the duct to a manometer containing water, and reading off the difference in height of the columns. The connecting tube should not project into the duct, and the edges of the test hole should, as far as possible, be free from roughness.

With metal ducts a measurement can be quickly taken by simply drilling a small hole (about \(\frac{1}{8}\) in.) in the duct and holding against it, without any leaks, the end of a piece of rubber tube connected to a manometer.

Concrete ducts are clearly more difficult to deal with, and it is best to arrange for test holes in ductwork in new installations through which
pressure-measuring tubes in corks can be inserted. The same holes can be used for thermometers for air-temperature measurement.

For measuring the pressure-drop across the porous floor of a ventilated silo, it is necessary to connect a measuring point immediately above the floor to one side of a manometer and one below the floor to the other. The under-floor pressure would be obtained by introducing a tube under the floor, probably through a convenient hole in the air-supply ducting, and the pressure above the floor would be measured either by a tube inserted through the silo wall and brought down to floor level, or by a form of spear pushed down from the top of the silo to the bottom. Such a spear is conveniently made of steel tube about \( \frac{\frac{1}{2}}{\text{in.}} \) diameter, with an overall length as required, and divided by airtight screwed joints into convenient lengths for handling and insertion under low roofs. The top end is arranged to accept a rubber tube for connection to a manometer, and the lower end is blanked off and drilled radially round the circumference with small holes to form the pressure-measuring point.

The under- and over-floor static pressures can of course be obtained separately, instead of reading directly the difference between them, and the over-floor static pressure will then indicate the pressure-drop through the grain in the silo. Variations in the over-floor static pressure will generally indicate local inadequacies in air supply to the bottom layers of grain, such as might be caused by poor local porosity of the floor, or inadequate distribution of air under the floor. If figures for the pressure loss in grain of various types at various depths and at various air flows are known, then, if the grain depth and the mean pressure over the bottom of a silo are measured, the air flow through the silo can be deduced and its intended performance checked. This method is not very accurate—probably within the limits of \( \pm 15 \) per cent.

**Use of Flowmeter**

The air flow through grain in ventilated silos can also be measured by means of a float type flowmeter in which a float is carried up a tapered tube by the passage of the air; its height in the tube indicates the air velocity. Such a flowmeter can be made with a very light float in the form of a disc so that its resistance to the passage of air is very low, and it can have a base suitably designed for placing on an exposed surface such as the top of the grain in a ventilated silo. An instrument of this type can thus be used for exploring the exit air from a grain surface, detecting any serious inequalities and assessing the mean velocity and total air flow through the grain. This method is probably liable to errors up to \( \pm 7 \) per cent.

**Moisture Content Measurement**

The moisture content of grain and other agricultural products is normally defined as the percentage of the total weight which consists of water. Less frequently the water contained is expressed as a percentage of the dry matter associated with it, i.e., of the total weight less the water.

From these definitions it will be clear that the most straightforward way of measuring moisture content is to heat a weighed sample of material, drive
oll the contained water and either weigh the remaining dry matter or con­
dense the water and measure it volumetrically. From the figures obtained the
moisture content can be calculated. Moisture content measurements in
laboratories, are, in fact, usually carried out by this sort of process, and with
proper care great accuracy is obtainable. For farm use, however, extreme
accuracy is not normally required, and it is desirable that the methods
employed should provide a more rapid result and use more robust, cheaper,
and more portable apparatus. Some of the methods used in farm practice do,
in fact, involve heating weighed samples but the apparatus is normally
specially designed to form a compact and easily used piece of equipment. The
accuracy is reduced as a result, compared with that obtained from laboratory
apparatus, but not to an extent which matters in practical work. Other farm
moisture testers do not measure moisture content directly but some other
property of the grain which is related to moisture content. Such meters are
calibrated by their makers against one of the accepted laboratory methods to
enable the user to convert the meter readings into moisture content values.

The measurement of moisture content with the accuracy normally
required in farming, which is probably between ± 0.5 per cent and ± 1.0
per cent, is not difficult if a suitable meter is used and proper care is taken.
Most of the moisture meters on the market have been carefully designed and
calibrated, though each one has its own peculiarities which are liable to lead
to errors if they are not respected by the user. It is quite possible, if a wrong
moisture content is obtained, that the error may be due to misuse of the
meter.

**Sampling**

In the first place, improper sampling of the bulk may easily lead to much
greater errors in assessing the mean moisture content of a quantity of grain
than any inaccuracies in the moisture meter used. If the average moisture
content is required, a number of samples must be taken from various parts of
the bulk and they must be thoroughly mixed before taking a subsample for
moisture measurement. This procedure is applicable when the moisture
content is required for sale purposes. However, if the grain is being inspected
to make sure that its condition is satisfactory during storage, then each
sample will need to be tested separately so that any wet patches can be
located.

It is useful, when measuring the moisture content of grain stored in bulk,
to have a sampling spear (Plate VI, lower) for takingsamples from any desired
depth in the grain. Such a spear consists of a small, pointed, hollow head
fitted to the end of a shaft which is conveniently divided into two or three
lengths for easy insertion under low roofs. The maximum length which can be
pushed into moist grain is about 10 ft, with a steel shaft of about 3 in. dia­
meter and a head of about 1 in. diameter. The hollow head is arranged to
remain closed so long as it is being pushed downwards, but on withdrawal an
opening is uncovered, allowing grain to enter the hollow space and be with­
drawn with the spear. The shaft may be marked off in feet to indicate the
depth of sampling. In addition to providing samples for moisture measure­
ment, the grain withdrawn can be inspected for signs of insect infestation or
mould development.
If samples are to be kept for any length of time before they are tested for moisture content they must be enclosed in airtight containers, which may take the form of glass or polythene bottles with screw tops, lever-lid tins, tins with press-on lids sealed with polythene tape, or polythene-film bags, which may be either heat-sealed or closed with adhesive polythene tape.

Number of Determinations

Whatever method of moisture content measurement is adopted, it is preferable to make more than one determination and take the average of the readings. If the readings (say three in number) are very different from each other, further readings should be taken until three consecutive ones are sufficiently close together. They should generally lie within the overall error of the meter used, i.e., if the meter is accurate to \( \pm 0.5 \) per cent m.c., the maximum variation between two of the three samples should be 1 per cent moisture content.

Milling the Sample

When a method of measuring moisture content requires grain to be milled, it must be remembered that the milling process itself can alter the moisture content of a sample if it becomes heated during milling. Mills should therefore be kept in good order, with their cutting parts sharp, so that they perform their function as rapidly and efficiently as possible. They should also be kept clean and be cleaned out between different samples.

Before using milled grain in a meter it should be mixed well, not only to ensure that fractions having different moisture contents are not used separately, but to ensure that one determination is not carried out with all the larger particles and another with all the smaller ones, which might lead to differing results with some meters. It should be remembered that milled grain may change its moisture content rapidly when exposed to the air, and if it is not used in the meter straight from the mill it should be sealed up. Mills of the coffee-mill type are suitable for sample milling and they may be either of the type which, in use, is clamped to a table, or of a smaller pattern which can be held in the hand, and when out of use can be carried in the pocket or in the moisture meter case. There is also a small motor-driven mill which is suitable for use where a large number of tests are carried out.

Whole Grain Meters

It must be remembered that most meters using whole grain are liable to give erroneous results if the grain is surface-wet or surface-dry. If there is reason to suppose that one or other of these conditions prevails, where the sample is a small one it should be kept in a sealed container after taking one set of readings, and further readings should be taken after half an hour or so. If there is a noticeable change, the process should be repeated until there is no further change. It is unlikely that such changes will persist for more than three or four hours. Where a sack or bulk of grain is being tested, the effects are likely to persist much longer, and readings over a period of 24 hours may be necessary.
Typical Moisture Testing Equipment

Descriptions of some moisture meters and equipment suitable for farm purposes and the precautions to be observed in their use are as follows.

Infra-red Meter. Meters of this type differ in detail, but the main features are common to all. The instrument consists basically of a balance with a single pan in which a given weight of milled grain is heated by an infra-red lamp situated above the pan. The pan and sample are counterbalanced either by a fixed weight, in which case the deflection of a pointer connected to the balance gives a reading of moisture content directly when all the moisture has been evaporated, or by adding weights to return a pointer to zero at the end of a run, the weights being calibrated in percentage moisture content. The time of heating can vary from 10 to 20 minutes approximately.

Meters of this type are influenced by mains voltage variations, by draughts, and by ageing of the lamp, but errors due to these causes can be minimized by leaving the meter in operation until there is no further change of reading, rather than by using it for a fixed time.

If used with care, this type of instrument can give results which are only bettered by using laboratory methods, but it is more suitable for use in a farm office than in the conditions usually found in a barn or drying shed.

Oil Distillation Method

In this method a weighed sample of whole grains (50–100 grammes) is covered with oil of high boiling-point in an open container, and the container and contents, together with a thermometer and stirring rod, are weighed. The container, oil and grain are then heated by any suitable means to a temperature of about 190°C (374°F), the oil and grain being stirred all the time, and weighed again, the loss of weight being assumed to be water lost by the sample. The duration of the test is about 15 minutes.

The oil used must not only have a high boiling-point, so that it loses no measurable weight of vapour during the heating, but it must also contain no water at the beginning of the test, and must not decompose at all during the heating process. Tea-seed oil, as used for fish-frying, etc., is suitable for the purpose and, though rather expensive, a proportion can be used several times if it is filtered clean after use. Apart from the particular properties required of the oil, the only other special need is a balance capable of weighing up to about a kilogram to an accuracy of about 1/10 gram. The source of heat, container for heating the grain and oil, and other items, can all take the form most convenient to the user. This method has the advantage that it may also be used for moisture-content measurements on grass, though it is not permissible with oily seeds, since other volatile matter may be lost during heating and erroneously classed as water in calculating the moisture content. Care should be taken in using this method, since the oil is highly inflammable.

Electrical Meters

Resistance Types

Some electrical meters, suitable for farm use, measure the resistance of a sample of grain as the criterion of moisture content. Two different types of meter working on this principle are available, one using a small unweighed
sample of milled grain (Plate VII(b)), and the other a large quantity of whole grain.

Those instruments using small samples of milled grain (the fineness of milling is not important) consist, basically, of a compression cell and a resistance meter. The compression cell, which incorporates a device for compressing the sample to a pre-determined pressure, contains two electrodes between which the resistance of the sample is measured. In one meter of this type, the deflection of the meter pointer gives a direct reading of moisture content: with another, a dial reading corresponding to the electrical resistance of the sample is obtained, and a scale provided on the instrument is used to convert this reading to a value of moisture content. A method of correcting the results for variation in temperature is provided, the temperature of the sample being the correct one to use, but since this cannot always be measured easily, the ambient temperature is frequently used instead. Normally these meters are battery operated for portable use, though one make can be equipped to work from the mains supply. The range of moisture content that can be measured satisfactorily with these meters is approximately 10 to 22 per cent, and the accuracy of the readings approximately ±1 per cent m.c. The chief precautions to be observed in using this type of meter are to keep the test cell clean, dry and undamaged, and to check the zero setting of the instrument regularly during use. Battery replacement becomes necessary when the zero can no longer be set, and the battery should be removed when the meter is stored for long periods. This type of meter is quite suitable for obtaining a reasonably accurate rapid measurement of moisture content.

A meter for use with large quantities of whole grain uses an assembly of pointed electrodes which are designed to be pushed through the side of a sack of grain, in which case the sample tested consists of the grain surrounding the electrodes. The required sample (nearly 3 pints) may also be taken from bulk and tested in the plastic container used for protecting the electrode assembly when out of use; or again, the electrode assembly may be pushed into the top of the bulk grain, when it will show the moisture content of the top, and not necessarily of the whole bulk. The nine electrodes of the assembly are connected together in groups of four and five, and the electrical resistance of the grain between these two groups is measured by an electrical insulation tester. This has scales for wheat, barley, oats, rye and maize and is direct reading in moisture content at 59°F: at other grain temperatures corrections have to be applied by the use of a chart supplied with the instrument. The meter is liable to give inaccurate results with surface-wet and surface-dry grain, and is prone to errors if the sample tested has a patchy distribution of moisture. It is, however, protected against the influence of a wet sack by the insulation of the probes for the 'outer' inch of their length. The useful range of moisture content covered is 13 to 25 per cent. This meter is useful for getting an approximate indication of the moisture content of grain in sacks with a minimum of delay.

Capacitance Types

These meters measure the permittivity (dielectric constant) of a small sample of the whole grain, the value of which varies with the moisture content of the grain; a weighed or unweighed sample is used, depending on
the particular meter used. The sample is placed in a rectangular cell two sides of which form the plates of a condenser, and the measurement is made using a high frequency alternating current. A knob and pointer, or rotating dial is turned until an indicator lamp lights and a value of moisture content is read directly from the scale or dial. A correction for grain temperature has to be applied to the instrument readings. This type of meter is battery operated. Using a good meter of this type values of moisture content between 11 and 28 per cent can be measured with an accuracy of less than ± 1 per cent m.c. The use of an unweighed sample reduces the accuracy of readings obtained with meters working on this principle, and samples should be weighed carefully in accordance with the maker’s instructions. After weighing the sample it should be poured into the test cell in the manner specified in the instructions. Surface-wet samples should be avoided whenever possible, but errors generally occur only when the grain has free water on its surface. Meters of this type are quite suitable for obtaining reasonably accurate rapid estimates of moisture content, and possess the added advantage that the useful range of the meter sometimes extends to high values of moisture content (e.g., 28 per cent).

Acetylene Gas Meter

This type of meter depends on the production of acetylene gas when the moisture in a milled sample reacts with finely-powdered calcium carbide. The meter consists of a pressure-tight container with a detachable top secured by a screw clamp at one end, and a pressure gauge graduated in percentage moisture content at the other. In operation a given quantity of carbide is placed in the body of the meter, and a weighed sample of milled grain is placed in the cap: the two parts are then put together in such a way as to avoid mixing the materials until the clamp has been tightened. The container is then shaken in accordance with the instructions and the percentage moisture content is read from the pressure dial, which is graduated from 3 to 26 per cent m.c. One scale suffices for all cereals and there is no temperature correction. The following points should be borne in mind when using this meter:

- the grain must be very finely milled, particularly when it is dry, otherwise a low reading will be obtained;
- the balance should be carefully used, and kept clean;
- the two parts of the mixing chamber must be thoroughly cleaned out after each test is carried out and, of course, they must be dry;
- the rubber gasket between the two parts of the container must be kept clean and in good condition to prevent leaks;
- the carbide should not be used when it is more than a year old;
- the instructions for shaking the mixing chamber should be followed closely;
- in accordance with the instructions, the meter should be warmed before taking a reading. This can conveniently be done by carrying out two determinations and discarding the first reading. If the meter is not warm, low readings are likely.

This type of meter is suitable for obtaining an approximate reading of moisture content: it should be noted that errors arising from misuse of the instrument are all likely to give low readings.
**Hair Hygrometers**

This type of instrument (Plate VII (d)) measures the relative humidity of the intergranular air in a mass of grain. An element made of hair is housed in a perforated tube and as the element shrinks or expands with changing humidity, its movement is transmitted by a mechanical linkage to a dial pointer. The tube, which may be up to 40 in. long, is inserted into grain either in a sack or in bulk. A concentric sleeve, either outside or inside the tube, can be rotated to cover the perforations in the tube to protect the element while the tube is being inserted, and to stop dirt getting in while the meter is not in use.

In use, the meter is inserted into the grain and the reading of moisture content is taken when the pointer has stopped moving; this may take up to half an hour. If the instrument dial is gently tapped before taking a reading this will ensure that a false reading is not obtained due to stickiness in the instrument mechanism. Scales are provided for the relative humidity of air (0–100 per cent) and the moisture content of various cereals (0–30 per cent); details of the scale vary with different makes of instrument. A good hair hygrometer can give readings accurate to approximately ±1.4 per cent m.c.; when using the R.H. scale for measurement of the relative humidity of air, errors are not likely to exceed approximately ±5 per cent R.H. As the meter shows the relative humidity of the humidity of the inter-granular air, no matter how accurate it is as a hygrometer, this type of instrument is liable to appreciable errors if the grain is surface-wet or dry, and one maker recommends that no readings should be taken with samples, for example, from a drier until 24 hours after drying.

This type of instrument is suitable for obtaining fairly accurate estimates of moisture content if a rapid result is not required. The relative humidity scale may also be used in the operation of a ventilated silo plant for measuring the relative humidity of the atmospheric air, so that a suitable temperature rise may be calculated; if necessary the relative humidity of the ventilating air can be measured by inserting the meter stem into the air duct. In this case it is preferable not to open the perforations fully in order to avoid damage to the element by the high velocity air.

**TEMPERATURE MEASUREMENT**

One of the difficulties involved in securing accurate temperature measurement in grain driers and silos is that, if a cool thermometer with a relatively large heat-capacity is inserted in a mass of warm grain, it will rapidly lower the temperature of the grain in its vicinity by removing some of its store of heat, and the low thermal conductivity of grain will prevent the replacement of this lost heat from the rest of the grain mass quickly enough to prevent the temperature falling. Similarly, a thermometer of high thermal conductivity inserted in a duct carrying warm air will read low because it is cooled by conduction to the outside atmosphere.

**TYPES OF THERMOMETER**

Thermometers can be divided into two groups. One group, which includes all the most common types of instrument, makes use of the expansion or contraction of various materials with a change in temperature. This group itself
can be subdivided into those instruments using a liquid or gas in a bulb, and those making use of the differential expansion of two metals, joined together to form a bi-metal strip.

Of the former the best known type is the common mercury-in-glass thermometer which may, in some cases, be protected with a metal shield. Other types are: mercury-in-steel with a capillary tube connection (which may be quite long), to a meter which is essentially a pressure gauge; and the rather similar type in which the bulb is part filled with a volatile liquid such as ether, again operating a form of pressure gauge through a capillary connection. These last types are often fitted with a recording mechanism in which a paper chart is moved by clockwork, and a trace of the varying temperature is drawn by a pen. The bimetallic type can be arranged for either indicating or recording, but the dial or chart must necessarily be arranged near to the measuring point.

The second group consists of electrical instruments, and includes thermocouples, resistance thermometers and thermistors. Of these, the latter two make use of the characteristic that, with certain materials, electrical resistance changes with varying temperature; in the case of the resistance thermometer, the material used is metal wire, and in the case of the thermistor a solid semi-conductor. Thermocouples, on the other hand, make use of the phenomenon that current flows in a continuous circuit made up of two wires of different metals if the two junctions of the wires are at different temperatures. In all three cases the thermometer element can be situated remotely from the measuring circuit, although leads of restricted length are required for thermocouples and resistance thermometers because of errors introduced by the leads. No such restriction applies to the use of thermistors, which also possess the advantage of responding much more rapidly to changes in temperature than the two other types of instrument. All three can be used in conjunction with a recording device.

Measurement of Grain Temperature

Careless use of all these types of thermometer can lead to false readings in grain. It has been shown for example that an unshielded mercury-in-glass thermometer should be left in an unventilated mass of grain for about a quarter of an hour before the reading can be relied on; any shielded thermometer will require at least half an hour and, in some circumstances, may never show the correct temperature. Thermometers of the bimetallic type or of the metal bulb and capillary type should never be used for grain temperature measurement for, owing to their high thermal conductivity, they will not measure the true grain temperature.

All three of the electrical thermometers can be used, if mounted in suitably designed heads. In the case of the thermocouple and resistance types, the element must be well buried in the grain and up to 15 minutes must be allowed after insertion for the correct temperature to be reached before a reading is taken; the thermistor gives an almost instantaneous correct reading. Some of the larger grain storage units incorporate fixed electrical thermometers in the storage silos, with facilities for obtaining an instant reading of temperature at any of the numerous measuring points; alternatively, a continuous record of grain temperature can be taken.
Measurement of Air Temperatures

For measurement of air temperature in a duct, all the above-mentioned forms of thermometer may be used, provided suitable care is taken.

Mercury-in-glass Thermometer

A mercury-in-glass thermometer is very satisfactory, apart from its fragile nature, for the glass is of low thermal conductivity, and the bulb temperature will not be much reduced by heat conduction down the stem. Mercury-in-glass thermometers are normally available in types known as total immersion and partial immersion. The total immersion type is used where the whole thermometer is immersed in the medium whose temperature is being measured (such as a room temperature thermometer) and having a scale along the whole of its length; the partial immersion type is used where only part of the thermometer is immersed (as in duct air temperature measurement), and in this case the temperature scale usually starts at or above the point to which immersion is made. For air duct measurements, a partial immersion thermometer (6 in. immersion is satisfactory) of the proper temperature range should be used so that the scale can be conveniently read while the bulb is immersed to its proper depth. Alternatively, a total immersion thermometer may be used with very little loss of accuracy, provided the temperature to be read appears far enough up the scale to allow a large part of the thermometer to be inside the duct.

Bulb and Capillary Thermometers

Bulb and capillary thermometers may be used, provided the bulb and a reasonable length of capillary are immersed, thus allowing the bulb, where the majority of the expanding fluid is present, to attain as nearly as possible the proper temperature. Both mercury-in-steel and vapour pressure types respond slowly to varying temperatures.

Bimetal Thermometers

Bimetal thermometers may be used provided the stem is not of too heavy construction and the sensitive bimetallic element, which in itself is of low thermal capacity and good conductivity, is not sheathed and is fully immersed in the air, together with some of the stem.

Electrical Thermometers

All three of the electrical types of thermometer can be used for measuring air temperature, provided that conduction of heat away from the element is kept to a minimum.

Control of Temperature, Humidity and Grain Moisture Content

Certain of the methods of measuring temperature, humidity and grain moisture content can be incorporated into control systems designed to regulate these factors, so that more rigid control of the drying process can be obtained, with resulting greater efficiency. Where grain cooling systems are installed, the use of cooling air can be regulated with reference to grain
temperature, air temperature and air humidity. Thermostats for controlling temperature, and to a lesser extent humidistats for controlling humidity, are in general use; increasing interest is being shown in the development of a rather more complicated control system with the object of regulating the moisture content of grain coming from a drier.

**Thermostats**

Thermostats for automatic temperature control may be based on any of the above-mentioned types of thermometer. They may be either of the two-position or on/off type, or of the proportional type. In the on/off type the whole of the heat available is switched on and off at varying intervals in order to maintain the temperature at the required level; in the proportional type the amount of heat used is varied continuously or in small steps to suit the needs of the system. When electricity is the source of heat, either system may be used, but with other sources of heat such as coke furnaces, it is necessary, for various reasons, to use the proportional method. The on/off method of control involves less complicated equipment than the proportional method and is quite satisfactory when applicable.

**Humidistats**

These controls are based on the hair hygrometer, with the hair element operating an electric switch through a suitable mechanical linkage. A typical application might be for the humidistat to switch on the heater unit in a ventilated bin system, when the relative humidity of the ventilating air rises above a certain level, dependant on atmospheric conditions.

**Moisture Content Controller**

A satisfactory type of moisture content controller has been developed, using a sensing element which measures the permittivity of the grain after it has passed through the drying section of a continuous-flow drier. With a suitable control unit the throughput of the drier can be regulated so that the grain is discharged by the drier at a reasonably constant value of moisture content. Far better control of the output moisture content can be obtained by this means than by manual operation.
Storage, Drying and Handling Structures

General Requirements

Buildings for housing the equipment to dry and store grain should be properly sited, carefully planned, and built to a reasonable margin of safety. They should be weatherproof, proof against ground moisture, and afford comfortable working conditions for the operatives. Possible sources of damage to the stored grain by vermin, pests and contamination from oil or fumes, should be guarded against, both in planning the building and in its construction.

Siting

It is important that the building is sited in a position that is convenient for bringing in the grain from the fields, and for the disposal of the stored grain, whether it is sold or processed and fed on the farm. Vehicles used for transporting grain in bulk are usually large, and tractor-drawn trailers need space to manoeuvre: for these reasons, ample space around the reception and dispatch sections of the grain store is essential. In most installations, some of the sub-structure is necessarily below ground level, and a dry site should be chosen where possible; so before starting to plan, a few trial holes on the proposed site should be dug. Construction work below ground level is costly, particularly if the water table is high, and as a general rule the building should be planned with a minimum of pit and duct work below ground level, so long as an efficient handling system is not jeopardized. On some sites it is possible to use the existing ground levels to advantage for loading grain in and out of the store, and to minimize the extent of the excavations. Where the water table is high, and site conditions are difficult, it will be much more economical in cost to keep the structure above ground level, rather than have deep excavations and expensive water proofing. Extension of the storage capacity and changes in drying and storage systems at some future date, have to be kept in mind when deciding on the site, and as a grain storage building is usually fairly high to the eaves, the possibility of leaving space for useful lean-to buildings on either side should not be overlooked. If the grain store is to be built near dwellings, there is a possible source of nuisance by noise from the mechanical equipment, and siting the fan so that it is screened from the houses can do much to obviate this. The proximity and extent of the electricity and water services and drains are other important considerations. In some cases planning permission may be necessary.

Pressure on Bin Walls and Foundations

The bulk densities of various types of grain and seed are given in Table A7 (in the Appendix).

The pressures exerted by granular materials are more complex than those
exerted by true fluids. Materials of this type are often referred to as 'semi-fluids'. In such materials, there is friction between the particles or granules themselves, and friction between the granules and the walls of the container. Thus, in addition to the lateral pressure of the mass of grain against the walls of the bin, and vertical pressure due to the weight of grain on the floor, there is a vertical force added to the walls, due to the friction between the stored grain and the surface of the wall. In deep bins there can be a considerable increase in pressure against the bin sides if it is emptied rapidly, though this is seldom an important consideration in farm grain stores, which are normally fairly shallow.

The relationship between the pressures or forces set up by grain was first shown in a formula devised by Janssen, which was subsequently developed into a simplified form by Jamieson, and for bins is expressed as follows:

\[ P = k \times w \times h \]

where \( P = \) lateral pressure in lb/sq. ft
\( k = \) a factor based on the ratio \( h/b \)
\( h = \) depth of grain
\( b = \) length of side between fixed points
\( w = \) weight of grain in lb per cu. ft

The values of \( k \) for different values of \( h/b \) are shown at Fig. 40. In this way, the force against 1 sq. ft of wall at any depth can be determined, and by adding the individual forces for each foot of depth and multiplying by the length of the wall, it will give the total lateral force against the wall.

There is also a relationship between lateral pressure against the walls and
vertical pressure on any part of the floor, which can be found by the formula (using the same constants) \( P = 1.67k \times w \times h \). The total load on the bin floor is the product of the area of the floor and the vertical pressure on unit area. It can be assumed that the portion of the total weight of the grain in the bin not supported by the floor is transferred into the side walls and then into the foundations in the way mentioned earlier.

The horizontal pressure at the base of bunker or thrust walls of varying depth for level and heaped grain can be worked out by Rankine’s equation, and values are shown in Table A9 (appendix) in which it is assumed that the angle of repose of the stored grain is 35 deg. and the weight of grain is 49 lb/cu. ft.

With the information available on pressures, it is possible to design bin walls to withstand these forces, but this is a job which should not be attempted except with professional advice.

The stresses set up by these pressures in the walls of a bin can be both compressional and tensional, and the materials used for construction must be strong enough to stand these stresses. Steel, aluminium, reinforced concrete, and timber, are all suitable materials to use for bins and retaining wall construction. Brickwork or concrete block walls are not suitable for withstanding tensional stress, and have to be adequately reinforced against it. Such reinforcing work is expensive, and the practice of building large brick bins has practically died out now that prefabricated ones are available. These bins are suitably designed and can be obtained in sizes for most farm requirements made so that they can stand under their own roofs in the open or ‘tailored’ to fit into existing buildings. Bins with built-in ventilating ducts and ventilated floors for bottom ventilation, and central ducts for radial ventilation through expanded metal sides, with all the necessary fittings made of the materials mentioned earlier, are obtainable.

FOUNDATIONS AND CONCRETE BASE SLABS

The weight of the bin and the grain contained in it are transmitted into the subsoil by the foundations or foundation slab. In order to determine the extent of the foundations, the safe bearing capacity of the ground has to be known, and Table A10 (Appendix) gives the approximate safe maximum loading in tons per square foot for various types of soil. The pressures imposed on the foundations in the normal type of farm bin storage installation are not particularly high, and are fairly evenly distributed over the base slab. On normal ground, a layer of concrete 6 in. thick, on a base of hardcore, thickened at the edges, is usually adequate. It is imperative that the base, to receive the concrete, is well prepared, and all soft patches dug out and filled with hardcore and consolidated. There is strictly no need to reinforce the concrete base slab against bending stress if the ground is firm, but a steel mesh reinforcement about 1 in. deep in the slab, is a precaution against surface cracking. In a large slab, expansion joints should be provided. The position of these is usually determined by the way in which the laying of the concrete is phased. Joints should be \( \frac{1}{2} \) in. wide with the slab thickened at the edges.

Special care should be taken with foundations on clay subsoils, as clay expands and contracts according to its moisture content, and this can cause
damage to the structure. Base foundations should be taken down to below the level to which the clay is affected by this shrinkage, either in mass concrete, or in the form of short friction piles. Where there are heavy point loads on the floor, such as the corners of high bins or bins with hopper bottoms where all the load is carried on the corner supports, machinery bases, or buildings on subsoils with very low bearing capacity (e.g., fen soils), the foundations need to be specially considered and the slabs designed accordingly. Deep piling may be necessary in some circumstances. Money is well spent on good foundations, since to replace inadequate or defective work at a later date is very costly.

With bins or silos of wide diameter and low height, the construction of the foundations on soil of good bearing capacity does not present a complicated problem, as the weight of the bin and its contents are distributed over a relatively large area. Usually, the concrete base is designed so that the outer part of the foundation, carrying the bin walls, is part of the base slab. High bins of small diameter impose a considerable surcharge on the ground, and foundations must be specially designed.

A further consideration in the design of the base slab is the possibility of moisture penetration into the grain on the floor at the junction of wall and floor, or through the base of the bin, particularly if the base is sunk below ground to assist emptying. Provision of a damp-proof membrane in the floor concrete is worth while.

STORAGE IN EXISTING BUILDINGS

Where grain is stored in sacks on the ground floor of a building, the building has to be weather-tight and the floor dry. These conditions are not always possible in existing buildings, as moisture can rise through concrete and penetrate through solid walls. Where floors or walls are damp, sacks should be stowed on timber over the floor and away from the walls. If the grain is to be stored on the first floor of a building, the floor and walls have to be strong enough to carry the stored grain. It would be unusual for a granary floor in the older type of farm building to be capable of safely carrying a superimposed load of 100 lb per sq. ft. Some older farm buildings are nevertheless suitable for grain storage, as long as their structural limitations are appreciated with respect to construction and condition.

Floors

The loading imposed by grain standing in a level heap or in sacks on the floor is given in Table A11 (Appendix) and ways in which a suitable existing building can be strengthened are shown in Fig. 41.

When assessing the strength of an upper floor, consideration should always be given to the walls and foundations carrying it. In older buildings, the walls were often built without foundations, and the mortar used for bonding the brickwork has deteriorated with age. The strength of simple timber beams can be worked out by equating the bending moment with the moment of resistance of the beam. If sacked grain is stored evenly on the upper floor of a building, the load can be considered as a distributed load, i.e., a load dis-
tributed evenly over the floor area, and for joists of rectangular section, the following formula applies:

\[
\frac{Wl}{6} = \frac{fbd^2}{8}
\]

where
- \( W \) = safe weight on beam in lb
- \( l \) = span of beam in inches
- \( f \) = safe fibre stress of beam in lb/sq. in
- \( b \) = breadth of beam in inches
- \( d \) = depth of beam in inches

The safe fibre stress of timber depends mainly on the species of the timber and its condition. For soft wood of reasonably good quality, \( f \) would be round about 800 lb per sq. in. In floors where the floor joists are carried on a main beam spanning across the building, the beam supports half the load carried by the joists on either side. When working out the strength of a floor, this beam should be considered first and the floor joists next. Point loads, that is loads which are carried at one point on the beam, can be considered as producing double the bending stress of an equivalent distributed load.

When strengthening floors with new beams under the existing joists, it should be ensured that the walls on which it is proposed to carry the beams are strong enough, and that the ends are not built into the walls over door or window openings, unless the lintels over the openings are strong enough.
Beams should be placed as near the centre of the spans as possible, and the ends carried on concrete padstones. To take an unserviceable beam out of a barn often weakens the structure, and it is sometimes better to leave it in position and fix the new beams to carry the floor joists on either side of it. The safe loading on Rolled Steel Joists (R.S.J.), and Universal Beams (U.B.) for spans suitable for farm buildings is given in Tables A12 and A13 (Appendix).

Granary floors can be strengthened considerably by the provision of struts or posts under the floor beams. The dimensions of the struts depend on their length and how they are fixed, but normally the number required to prop up a granary floor is so few that over-estimation of the size is not wasteful. Square or circular sections are best, and 6–8 in. diameter timber posts, or the equivalent area in square sections, are usually suitable for the short lengths required to support the average granary floor; railway sleepers are useful for this purpose. Struts should always be fixed with a cap or spreader at the head, and on a firm foundation at the base. They should be placed as near as possible to the centre of the span of the beam they are intended to support. This is not always convenient as it may restrict the use of the lower floor but with a little adjustment it may be possible to fit the posts into the layout of the building. It is often advisable to fix posts under beams close to the old walls supporting the beam, as this reduces the load on the walls and on the length of beam built into the wall, where deterioration is most likely to have occurred.

New upper floors in farm buildings to be used for grain storage purposes should be designed to carry a superimposed loading of at least 200 lb per sq. ft. Floors can be constructed of steel, concrete or timber, or a combination of these materials. It would be exceptional if a suspended floor with this loading capacity could be safely carried on the walls and foundations of a farm building not specifically designed to support it. Many existing granary floors can be strengthened or propped up to carry a load of about one cwt per sq. ft, but if a loading greater than this is contemplated, the floor would normally have to be supported independently of the walls.

Advice

Work of this sort should not be undertaken without proper advice from someone who is qualified to give it, and the advice should be followed even to the extent of marking the depth on the wall to which it is safe to store the grain. Mechanical handling methods make it easy to build up the load on a floor to beyond the limits of safety, and this can have serious results.

Storage in Bins

Most types of pre-fabricated bins are made with walls that are weatherproof, and there is no objection to the sides being exposed. Some are built to carry their own roof, which can be extended to form a cover for the working parts of the storage installation. Others, of the circular type, are free standing with conical roofs, and are suitable for outdoor storage in the most adverse weather conditions. Where cover is necessary, framed buildings of the Dutch Barn type, of steel, timber or concrete construction, cladded as required, are suitable. The building over the bins has to be ventilated and adequately illuminated, and driving rain prevented from blowing under the eaves into
the tops of the bins, by side cladding. Cladding to the full depth, or cladding over a dwarf wall with adequate door openings for access into the building, is usually necessary to protect the equipment and working space. A number of efficient storage plants have been installed in existing buildings of the traditional type, but when considering these buildings for grain storage, it should be remembered that the only value that most of such buildings usually have is that they provide a cover. Where bins are squeezed into existing buildings, it is often difficult to avoid leaving inaccessible spaces which are impossible to clean out: adequate room should be left between bins and walls for cleaning. Sometimes the siting and tie-up with other buildings may justify the adaptation of existing buildings, and there may be aesthetic considerations to take into account.

**Arrangement of Bins**

A sufficient number of bins should be erected to hold the quantities of grain which it is expected to store on the farm, and it is generally advisable to provide some additional capacity for turning over or bulking the grain. The capacities of the individual bins making up the batch depend on the type and quantity of grain to be stored; there is usually no difficulty in obtaining bins to meet all requirements.

Farm installations generally consist of bins in two rows with a central space between for the conveyor emptying the bins. This space is sometimes 'roofed' over to form a tunnel between the bins with small holding bins above. Alternatively, the parallel rows of bins can share a 'party wall', with the conveyor duct below ground level or built into the walls of the bin, thus saving the cost of one wall down the length of the unit, and increasing storage capacity. Some arrangements of bins are shown in Fig. 42.

Bins can be arranged in lines so that they are served by a single top and bottom conveyor, with elevators to serve the pit, cleaner and drier, and to take grain from the bottom to the top conveyor. They can also be grouped around a central point where the grain is off-loaded into a shallow pit, and thence to an elevator which serves each bin in turn on a radial plan. With rectangular bins, the total capacity of a storage unit of this type is limited.

In a ventilated bin plant, harvested grain is loaded direct into bins and dried in situ, and in plants of this type, bins are normally grouped together. With batch or continuous driers, it is important to provide holding bins to supplement the grain reception and keep it in phase with the capacity of the drying arrangement. The bin group is therefore sometimes split, in larger installations, with the drier between the pre-drying and holding bins. Pre-drying or holding bins can also be used for bulk holding quantities of grain ready to leave the storage or for turning over the grain from bin to bin, and for this reason the expense of providing hopper bottoms to these bins for ease of emptying is well justified.

Bins are usually circular or rectangular in plan. Where they are to be contained in a building, circular bins require about 25 per cent more cover than a group of square bins and so need a larger building. Square bins with sides of 10 ft holding about 2 tons of grain to each foot of depth up to a height of 20 ft are a popular size. Larger rectangular bins are available, though some need tie rods. Final clearance of grain can be difficult owing to the larger
Fig. 42. Arrangements of bins
floor area. Circular bins are available up to 50 ft diameter and greater. In circular bins, most of the stress in the wall is tensional, and for this reason the larger capacity bins tend to be cheaper to construct.

**Self-emptying Bins**

Self-emptying bins can be constructed by filling the bottom of most of the standard types of prefabricated bins with hardcore, and shaping the surface in concrete to the required slope; or by building a framework made of steel, timber of concrete sloped to the required angle, and surfaced with planking or cladding. Alternatively, hopper bin bottoms, which stand on their own supports with the outlet at any reasonable height above floor level, are available from most manufacturers. Where hopper-bottomed bulk holding bins are used for filling grain tankers, the level of the outlet should be 15 ft above road level, and there should be sufficient space for the tanker to move under or alongside the hopper. It is generally accepted that a minimum slope of 15 deg. is required if a grain hopper is to empty completely. Bins with hopper bottoms are expensive to construct and wasteful in bin capacity, and should be built as high as practicable, as it is cheaper to build higher to achieve a given capacity over a hopper than to extend the area of the bin, and the hopper.

**Types of Bin**

Bins of various sizes, both circular and rectangular, made of steel or aluminium, can be purchased in prefabricated sections to meet most farm requirements. The rigid and air-tight walls, designed for easy handling and erection on a prepared base by unskilled labour, are made of flat or corrugated pressed metal sheets bolted to vertical and to horizontal supports, or seam bolted. Alternative features are available, such as built-in tunnels and trunking, ventilating shafts, and ventilating floors, together with fittings for access to the bin and handling the grain. Metal bins are also manufactured in expanded metal with a central drying cylinder.

Reinforced concrete bins can be built to practically any requirements, but the designs should only be carried out by someone who is experienced in the design of reinforced concrete, and the building work should be done by skilled labour. On the other hand, precast concrete units, in the form of panels or staves for bin construction, are available for erection by farm labour. The staves are made up into circular bins bound with steel tension bands obtainable for bins of up to 20 ft diameter and 20 ft high. The staves are tongued and grooved in order to keep the sides watertight, and this also simplifies erection. Concrete stave bins or silos larger than these dimensions are a job for skilled erectors. Rectangular precast concrete bins are made up with tongued and grooved panels, supported by reinforced concrete posts at each corner, and are available for bins up to 10 ft square and 30 ft high. Concrete is a material that requires no maintenance.

Timber is suitable constructionally for grain storage bins, as it is strong both in compression and tension in relation to its weight, and is elastic within limits. It is a durable material, understood by most people who build, and can be handled and put together without special tools. For these reasons it is
popular with the farmer for making small holding bins, or retaining walls for floor storage, either fixed or movable. Prefabricated storage bins and wall sections made of timber in the form of planking, plywood and reconstituted timber, can be purchased at reasonable cost in similar sizes to bins made of other materials.

Bins made of brick or concrete blocks are expensive to build, and the materials and standard of workmanship have to be of high quality. Construction in these materials is only justified for the smaller bins or for building bins where some restriction in dimension or other reason prevents other types of bins being used, or for strengthening existing walls.

Brick bins with 9 in. thick walls should be reinforced against tensional stress in every course with high tensile steel reinforcement overlapping at the corners, or with the equivalent in mild steel. Where 9 in. hollow concrete blocks are used, in addition to the bed joint reinforcement, vertical reinforcement in each corner and in the centre of each wall is necessary. This reinforcement is in the form of four \( \frac{3}{8} \) in. rods in the cores of the blocks carried down into the foundations, and the cores of the blocks filled with weak concrete, forming a reinforced column. Reinforcement in the way described is only suitable for \( 10 \times 10 \) ft bins up to 12 ft high. Bins larger than this, with 9 in. walls, need to be cross tied and should be considered as special designs which require expert structural advice. Large-capacity circular bins have been built in reinforced brickwork \( 4\frac{1}{4} \) in. thick, but this construction is a highly skilled job.

Brick and concrete walls are not always weatherproof, and bins should be rendered internally if the walls are exposed. Another advantage of rendering is that it reduces the risk of infestation, and prevents air loss through the walls in ventilated bins.

Temporary bins can be made up with steel mesh in the form of a cylinder, or supported on a timber frame forming a cube which can be lined with hessian or building paper. Other small bins have been made up on the farm with curved corrugated iron roofing sheets, seam bolted and bound with shrouded steel wire ropes.

**Grain Outlets**

The best position for the grain outlet in the floor of a square or circular bin is in the centre, but where two lines of bins share a common conveyor tunnel a central outlet will necessitate a deep tunnel in order to obtain sufficient fall on the outlet pipe and allow for the height of the conveyor above the tunnel floor. As a general rule, outlets should be placed as near the centre of the bin as possible, with due regard to tunnel depth. Labour required for the final clearing out of grain from a flat-bottomed bin can be reduced by the provision of additional floor outlets, and by a slope on the floor. A funnel-shaped or slotted mouth to the outlet is also an advantage. Discharge of grain from the side of a bin is faster than from an outlet in the bottom, but to empty the bin completely, more manual cleaning up is required. Most bin manufacturers supply prefabricated outlets with a control valve, and they are usually about 30 sq. in. in area. Outlets can be made up of welded steel sheet in the form of square or circular tubes with a slide control, or of any type of pipe which is strong enough and has smooth sides.
Flat-bottomed bins can be emptied by the use of augers which may be inserted into the bins through built-in tubes which lie horizontally in the base, or through inclined tubes leading to a small sump in the base of the bin. Some circular bins are fitted with a sweep-arm auger which conveys the grain to a central discharge point and fully empties the bin without any manual labour. Emptying the bin can also be assisted by air through the ventilated floor (Plate IV).

**Grain Pits and Tunnels**

An important part of the installation is the receiving pit into which the grain is loaded from the fields for conveying to drying and storage. In some cases pits are also used for bulking during the storage period, for loading, or for turning over from bin to bin. Pits should be roofed or protected from the weather, and the roof should be high enough to enable the transport vehicle to be fully tipped over the pit. The size of the pit depends on the conveying system, and it may be sufficient simply to provide a hopper for directing the grain into a high capacity elevator, the size of the hopper depending on the rate at which the grain is brought in and the machinery to deal with it. A spillage area under cover around the pit, so that the grain can be tipped on a dry concrete floor and pushed or augered into it when required, is extremely useful. Where the grain reception pit is required for holding undried grain, it is sometimes made large enough to take several hours’ output of the combine. The better alternative in plants with a drier is to provide holding or pre-drying storing capacity in the bin to serve as a buffer between the field and drying plant. A small pit is much less costly to build and easier to keep dry than a deep one, and for this reason there is rarely need for the grain reception pit to be anything more than an extended mouth of the conveyor system, sometimes divided to handle more than one crop at a time, of little more capacity than that of the vehicles bringing in the grain.

Brickwork or concrete block on a concrete base, or reinforced concrete, are satisfactory ways in which to build the pit. Waterproofing is important and, if the ground is at all wet, a layer of asphalt (laid by a specialist firm) or some other form of impervious lining incorporated in the construction, or a steel lining tank, is necessary. Polythene sheeting can be used. Where the site is dry and the water table low, it may be sufficient to mix a waterproofing compound in the concrete: providing the concrete is thick enough (6 in.) and properly laid, the pit should be reasonably dry. Tanks made of welded steel plates make very satisfactory reception pits provided the outside face of the steel is treated with rustproofing material before the tank is sunk into the ground, and care should be taken that it is firmly anchored down, or the rising water table may float it out of the ground. To avoid deep excavations it is sometimes helpful to construct the reception pit partly out of the ground and drive up to it or over it on a ramp which should not be steeper than 1:6.

Movable steel hoppers incorporating a horizontal auger, free-standing on the concrete floor when in use, are an alternative to a permanent pit. Augers can also be built into permanently constructed pits to reduce the depth for a given capacity as the pit can be made longer and only two of the sides need to be sloping. If the ground levels are suitable, and an outfall to a ditch or drain is obtainable, it is worth installing a drain below the level of the sub-structure.
The drainage trench is filled with hardcore and forms a free draining area from which all the ground water runs into the pipe at the bottom. Types of grain reception pits and hoppers are shown in Fig. 43.

Tunnels below ground level should be constructed of brickwork or reinforced concrete with precautions against water percolation where necessary. Heavy polythene sheeting has been effectively used for keeping damp out of underground tunnels; the excavation is lined with polythene and the tunnel structure built within it. The concrete floor or the tunnel should be laid with a slight fall towards a sump, so that any water can be localized and dealt with by a small pump if necessary. When designing the tunnel roof, the loading it will have to carry has to be carefully considered, particularly where there are point loads, e.g., the corner stanchions of bins, carried on the tunnel roof. It is nearly always desirable to offset the tunnel so that the 'party' wall of a group of bins is carried direct on one wall of the tunnel, thus reducing the load on the roof. It adds considerable strength to the tunnel construction if the roof reinforcement is tied to the walls, and the floor is built as a reinforced concrete slab.

BUILDINGS FOR FLOOR DRYING AND STORAGE

Advantages and disadvantages of drying and storing grain on the floor are discussed in *Choice of Drying System and Planning of Installations and Drying Grain in Bulk*, pp. 27–41, 62–82.

The Building

Dutch barns, and some more of the traditional type of buildings found on the farm, can be used for floor storage, provided they are suitable from a structural viewpoint and can be adapted at reasonable cost. New buildings should be of the rigid frame or portal type of construction, in steel, timber or concrete, with the stanchions and foundations designed to support the walls retaining the grain, unless these walls are to be self-supporting. Buildings of the rigid steel panel type are also satisfactory for floor storage, and can be an attractive proposition. From the viewpoint of drying, loading and economic building cost, the depth of the grain stored should be about 7 ft deep, and retaining walls up to 8 ft high are usually sufficient. Above this height the sides of the building can be cladded up to eaves' level with sheeting. If the grain is to be dried on the floor, the top of the heap should be level; but if pre-dried, it can be banked up to increase the holding capacity of the building. The building has to be a dry one, and it should be remembered that snow penetrates where rain will not. Cladded asbestos roofs with pitches of under 22½ deg. should have the laps adequately sealed, and filler pieces should be fitted where corrugated sheets meet straight components: this also helps to keep the building bird proof. An adequate system of disposing of the surface water from the roofs and pavings around the building is essential, and valley gutters should be avoided in the design.

Sufficient lighting for working in the building can be provided, but the extensive use of roof lights is undesirable. Birds dislike a dark building so natural lighting should be kept to the minimum; there is also a risk from condensation on the roof lights. Artificial lighting is necessary, and ample
Fig. 43. Types of grain reception pits and hoppers
power points for augers and other mechanical equipment are needed if long lengths of unprotected electric cable lying on the floor are to be avoided.

Doors at one or both ends of the building are necessary in the larger stores and some side doors can be an advantage. When the store is full, provision should be made for movable walls to take the pressure off the doors; and if the walls are of brick, piers should be built on either side of the door openings with steel channels to support the movable wall sections independently of the brickwork.

**Size of the Building**

The dimensions of the building are determined by the quantity of grain to be stored, the working space required, the layout of the floor ventilating system, and any additional space required for other use, as the building is basically a 'general purpose' one. About 6 sq. ft of floor space is needed to store a ton of grain 8 ft deep, and for heaped grain an angle of natural repose of 35 deg. may be assumed. Grain on the floor is dried by a system of lateral ducts fed in from a main duct, and their layout influences the optimum span of the building. There is a practical limit to the effective length of lateral ducts, and this generally limits the span to a maximum of 40 ft for a building with a single side of lateral ducts. Buildings of larger span need a main duct above or below the floor down the centre of the building, and laterals on either side. Large loaded vehicles enter and move about inside the building, and augers are used for loading the grain, so ample headroom at the doors and inside the buildings is essential: minimum eaves height of 14 ft is suggested. It may be an advantage, in certain circumstances, to provide a conveyor mounted under the ridge of the building for bringing in and spreading the grain; in these circumstances a fairly high roof is an advantage, as the higher the conveyor, the greater the spread. Typical layouts of floor storage installations are shown in Fig. 44.

**Floors**

The concrete floor of the store is normally of 6 in. thick 1:2:4 concrete, and should be above the level of the adjoining ground and laid to a very slight fall towards the doorways of the building. Pavings should be laid so that water does not enter the building. If concrete to the mix specified is properly laid and consolidated, it is waterproof, but this does not always happen and a damp-proof membrane should be included in the floor construction. Bitumen and polythene sheeting are suitable for this, with the damp-proof membrane carried into the wall thickness. An effective method is to use 500 gauge polythene sheeting with at least 12 in. laps, laid on a level 2 in. bed of sand over the hardcore, and the 6 in. concrete slab over this. The preparation of a firm base before the concrete is laid is again emphasized, and the advisability of including reinforcement and expansion joints is mentioned earlier. Floors with built in lateral ducts below floor level have been used, but the work is expensive and the ducts interfere with the general purpose nature of the building. Some possible methods of construction are referred to in Drying Grain in Bulk.
Fig. 44. Typical layouts of floor storage installations.
The retaining, or thrust walls, holding the grain have to be designed and built strong enough to resist the pressure, or there will be structural failure. Pressures depend on the weight of the grain and the depth to which it is stored, and whether the top of the stack is level or sloping. This is a very important consideration, as grain heaped on a level stack can impose a considerable surcharge on the walls. It should always be remembered that, when the walls are only designed for level grain storage, they should only be used in this way.

Types of thrust walls are:

- reinforced brick or concrete block walls between posts or buttresses;
- reinforced ‘in situ’ concrete walls;
- post and panel walls in a variety of combinations of timber, concrete and steel;
- mass walling;
- ‘L’ shaped walls of the balanced cantilever type.

Brick or concrete block walls are not suitable for withstanding tensional stress, and unreinforced brickwork owes its strength only to its weight and thickness; grain should not be stored more than 3 ft deep against a 9 in. unreinforced brick wall, and only then when the wall is soundly built. For walls to support grain up to 8 ft deep, the brickwork should be 9 in. thick and built on firm foundations and between supports at 7 ft 6 in. centres (e.g., the stanchions of a rigid frame building, suitably designed buttresses, or brick piers). It should be reinforced with two no. 6 g. high tensile steel wires set ¾ in. from the wall face in every course up to half the height and every other course thereafter or other reinforcement of equivalent strength. In some types of brick walls, reinforcement is only needed in every other course for the full height. The reinforcement should be continuous throughout the wall, either through or around the supports. A damp-proof course is necessary in the wall, and it should be built in blue engineering bricks reinforced as before.

Concrete blocks are not always comparable to clay bricks structurally, and additional vertical reinforcement, in the form of ½ in. rods in each core of the blocks, is necessary. These rods should be properly secured into the foundations, and the cores of the concrete blocks filled with concrete. Walls in brick or concrete block are not necessarily weatherproof, and rendering, or protection from the weather by extending the wall cladding, may be necessary. Like some brick walls concrete block walls are air permeable, and need rendering to avoid the escape of air during drying.

Reinforced concrete walls 8 ft high, supported every 7 ft 6 in., need to be at least 7 in. thick and reinforced horizontally and vertically at intervals of not less than 12 in., with ¾ in. diameter M.S. rods or their equivalent in steel mesh or high tensile steel reinforcement. Walls should be constructed as one with the foundations, with the reinforcement carried down and turned into the floor. Reinforced concrete can be used for continuous wall construction, i.e., walls without the need for support by intermediate piers or buttresses, but these are special designs.

Post and panel walling is an attractive form of construction. Walls and wall units in permanent or movable construction in various materials can be obtained at reasonable cost. Some designs depend on the parent building for support, and some are self-supporting. The strength of a post and panel wall
Fig. 15. Types of grain retaining wall construction
depends on the rigidity of the posts supporting the panels, and these supports must be firmly anchored. Standard 15 ft bays in framed buildings are too wide to span with single wall units, and intermediate supports are nearly always necessary. The suppliers of the framed building should always be consulted, if it is intended to support the walls on the frame and stanchions, and foundations designed to take the increased loading. For walling without vertical supports, the wall section has to be continuous with the foundations forming an 'L' shaped slab, so that the toe of the wall carrying the weight of the grain is held down and partly supported against the lateral pressure. Timber can be used for making walls of this type, and movable wall sections are available which are self-anchoring by friction on the floor. Concrete wall sections of similar design are also manufactured.

Subdivisions

Subdivisions are used for dividing up the storage floor. The operations of the plant are more flexible if the wall sections can be moved to any position on the storage floor, rather than provide fixed lines of holes or anchorages into which the posts to support the walls are inserted. Holes in the floor can also form harbourage for grain pests, and should be avoided if possible. Mobile timber units are light and easy to handle, and can be designed so that they fold flat for storage. For demountable partitions on fixed lines, light steel stanchions or channels welded back to back, held by sockets in the floor with planks slotted into the webs, are satisfactory. Second-hand timber floor sections from hulking supported by posts of steel or timber, are a cheap method of providing temporary walling, and can be useful in existing buildings to distribute the thrust of grain stacked against walls. For this purpose, they are best fixed leaning slightly inwards. Walls built of sacks or straw bales can also be used for temporary internal subdivisions of the floor.

Air Ducts

Main air supply ducts are subject to pressure when the fans are working, and they must be air-tight and strong enough to resist this; and if below ground, the ducts should be reasonably waterproof. In a layout with a single side of laterals, there is little point in building the main duct below level ground, and it is normally placed along one wall of the building. If ducts are built inside the building, it should be remembered that the walls may have to retain the grain, and they should be built accordingly. Main ducts in the centre of the building with a lateral duct layout on either side can be above or below ground—a duct below floor level is out of the way, and the floor space can be used more fully.

Walls of ducts should be built of sound 9 in. brickwork with piers at 15 ft centres. This construction can be suitable for above or below ground, but as the roof of a duct below ground forms part of the storage floor and will be subject to heavy loading, the concrete needs to be properly reinforced and carried over the walls. For outside ducts, concrete in slab form is suitable for the roofs, providing the slabs are firmly held down. Alternatively a sheet of expanded metal fixed to both walls of the duct will serve as shuttering and reinforcement for a permanent concrete roof, and can be rendered smooth on
the inside. The flow of air from the main duct to chosen sections of the floor is controlled by valves in the tunnel as described in *Drying Grains in Bulk*.

Factory-made main air ducts made of steel or timber, with spigots or openings for connecting to the lateral duct system, some fitted with control doors, are obtainable. The ducts are usually fixed to the floor with foundation bolts, and can be moved to free the floor.

**Ventilation**

It is generally accepted that in ventilated bins and floor drying and storage plants, outlet ventilation of 1 1⁄2 sq. ft to each 1,000 c.f.m. through the fan is satisfactory. The outlets should be dispersed over the drying area and can be in the form of ridge ventilation, ridge ventilators, or ventilation through the gable of the building. Any form of outlet ventilation should be bird proof.

For systems using grain driers, the ventilation is mainly tied up with the drier, and special arrangements are needed. If fans are used, they should be adequate in size and sited so that they exhaust the air to the outside and not merely recirculate it in the building.

**Building the Store**

When building a grain drying and storage building, it is advisable to have one party with overall control over the job, as close co-ordination between the various subcontractors (steelworker, builder, engineer, electrician) is important. If the owner employs a professional adviser, the latter can take this responsibility. Alternatively, the owner can take control and carry out the work with the aid of his advisers.

A number of manufacturers will provide a design and estimate for a bin or floor storage installation erected complete. This method of carrying out the job has the advantage that the firm takes the responsibility for erecting the building, making it work, and keeping it working through the maintenance period. Other firms, who supply or install grain drying and storage equipment, are prepared to provide similar services in this respect.

It is important to allow plenty of time for planning the installation. Preliminary investigation of the site is well worth while, and it would be preferable to resite the building, rather than have a battle against water or running sand. Firm estimates for the various items of the contract are important and, if the firms tendering are given adequate details and sufficient time to prepare their tenders, the estimates are more likely to be realistic.

**Buildings for Chilled Storage of Grain**

A possible alternative to drying is chilled grain storage, and as far as can be foreseen the buildings for this do not differ greatly in layout from those used for drying and storage. General requirements of buildings for this purpose are discussed in *Cooling Grain to Maintain its Condition*.

**Sealed Storage Bins**

Requirements for sealed storage of moist grain are described in *Airtight Storage of High Moisture Grain*. 
Normally the bins made of steel or concrete are sited adjoining the areas where the grain is fed or prepared for feeding. Ample space around the bins is necessary for using the equipment for filling and emptying. Bins should be kept shaded if at all possible, to avoid fluctuations in pressure and movement of air in the bin due to solar heat.

Tall bins impose a heavy load on the ground, so the design of the foundation base is a job for someone qualified and experienced in work of this nature. Once the foundation has been made it is difficult to strengthen, so it is prudent to make the design suitable for some future need to increase storage capacity by heightening the silo.
Control of Pests

ONE of the hazards of storage is attack by mice, rats, birds, insects and mites. It is all too frequently assumed that some loss from pests is as inevitable as losses to the growing crop from causes outside the farmer’s control. It is the intention to show that this is not so, and to indicate the means by which grain may be stored indefinitely without damage by pests.

RATS AND MICE

If buildings are proofed against entry by rats and mice, and a high standard of hygiene is maintained outside, these rodents will find no food or harbourage. Within buildings, all grain and feeding-stuffs should, wherever practicable, be stored in rat- and mouse-proof containers.

It is possible that rats and mice will sometimes find a way into even the most carefully proofed, hygienically maintained, buildings; this may happen, for example, when a door is inadvertently left open. When rodent pests get into grain stores, some grain will be eaten (or partly chewed, which greatly reduces its value) and some will be fouled, expensive sacks will be damaged and soft metal as well as woodwork in the buildings gnawed. Damage can result from rats gnawing electrical cables which may also lead to fires. Another rodent-borne hazard is that of disease, particularly leptospiral jaundice (Weil’s disease) to which agricultural workers are especially vulnerable.

The presence of rats and mice inside buildings may be detected from various signs: gnawing marks, spillage from bags, footprints, greasy smears, hairs and droppings. Outside, holes and runways may be seen in banks, hedgerows and ditches.

The rodents most often encountered in and around farms are the common rat (Rattus norvegicus Berk.) and the house mouse (Mus musculus L.). These may breed continuously throughout the year, the normal litter containing five to eight young, which mature within three months of birth. They will live in any fairly undisturbed harbourage where there is access to food and water. Since there is a general movement in from the fields during the autumn, when food outside is scarce and the weather cold and wet, buildings are liable to become more heavily infested just when most grain is in store. The stored grain may then act as both food and harbourage.

Once rats and mice are detected on farms, inside or out, they should be destroyed, and it is important that the whole of the infested area should be treated at the same time. The most effective method is by poison baiting, preferably with one of the blood anticoagulant rodenticides, such as warfarin, which act painlessly by causing intractable bleeding when small quantities of poison are eaten over a number of days. Because several doses of an anticoagulant are necessary to kill, this technique may be slower than poisoning with one-dose poisons such as zinc phosphide and arsenious oxide that are still sometimes used. For the same reason it is safer for farm animals which, if normal precautions are taken, are unlikely to eat enough bait to be harmed.
FARM GRAIN DRYING AND STORAGE

It is also a surer method, for rats and mice will go on eating it until they die. Pre-baiting, such as is practised with quick-acting poisons, is unnecessary.

A few warfarin-resistant populations have been discovered recently. These can be cleared with quick-acting poisons.

Small infestations can often be cleared with break-back traps. Gassing powders are also very effective but these are suitable only away from buildings.

BIRDS

The most common pests of farm grain stores are house sparrows (*Passer domesticus* (L.)) and domestic pigeons (*Columba livia* Gmelin, Var.) which have gone feral. Neither will become serious pests where the area surrounding the grain store is kept clean, since they are usually attracted in the first place by spillage and other waste food.

Grain storage buildings should be kept as dark as possible inside, so as to discourage birds from entering when doors are open, and otherwise adequately proofed.

The Protection of Birds Act, 1954, removed protection from both species so that they may be killed by an owner, occupier or authorized person.

Both pigeons and house-sparrows can be caught in cage traps and, where the situation permits, shooting of birds which have been attracted to a grain bait is also an effective method of control. Further information on the control of house-sparrows is given in Advisory Leaflet 169, *The House Sparrow*, obtainable from Her Majesty’s Stationery Office.

INSECTS AND MITES

GENERAL

Fortunately, in this country, insect pests of stored grain do not come in with grain from the fields, so that preventive measures applied to the storage buildings offer a good insurance against trouble. Certain species of mites, however, may occur out in the fields and these may be carried into the stores with the harvested grain, but these are soon replaced by indoor species.

Insects cause loss in farm-stored grain both by direct attack and by causing it to heat. Insects and mites eat the endosperm and germ, causing the grain to lose weight, food value and ability to germinate. De-germed grain is useless for seed or for malting. Contamination of wheat by insects, rats, mice and birds makes it unsuitable for milling flour which must have a low insect fragment or rodent hair count. Mites can taint grain with an unpleasant secretion which is difficult to remove. Such tainted grain may be unpalatable to farm stock. Some millers, agricultural merchants and maltsters may refuse grain in which only a few insects are found or purchase at a reduced price, especially if the parcel in question is to be kept in store for some time or merged with other stocks.

The activity of insects within a bulk of grain may cause it to get hot. Such heating is usually concentrated at first in certain ‘hot spots’, which are centres of insect breeding and where the grain may originally have been damper than elsewhere. Eventually the hot spots merge and the insects, which by then will have raised the temperature to about 108°F, are driven to the out-
side layers. Associated with the heating is movement of water from the hot centre to the cool periphery, with resultant attack by moulds, caking or even sprouting.

In such cases, fumigation with gas may kill the insects and so stop the heating, provided it has not changed over into damp grain heating caused by fungal attack, which can only be dealt with by redrying or cooling the grain. It is important to distinguish between the two kinds of heating. Grain which has suffered badly from heating is unsuitable for flour manufacture, malting or for seed.

**Biology**

The insects and mites which occur in grain are not spontaneously generated but are produced from eggs laid by the female parent after mating. They can keep going in small numbers for long periods in empty unheated granaries and then multiply rapidly under favourable conditions when grain is stored, especially if the temperature is $70^\circ \text{F}$ or over. Being very small and preferring darkness to light, they are usually not noticed until an outbreak occurs.

Many kinds of insects and mites occur in farm granaries. The most important today is the saw-toothed grain beetle (*Oryzaephilus surinamensis* (L.)), but the grain weevil (*Sitophilus granarius* (L.)), the rust red grain beetle (*Cryptolestes ferrugineus* (Steph.)) and the flour mite (*Acarus siro* (L.)) can also cause damage. The beetles pass through four stages of development—egg, larva, pupa, adult. The egg of the grain weevil, laid in a very small hole chewed by the female in the skin of the grain, develops into a legless grub which bores in the floury part. Those of the other two beetles, laid in cracks or on the surface of grains, develop into active legged larvae which live between the grains and burrow in the germ. There is some evidence to show that the saw-toothed grain beetle gets established more readily in grain which contains much dust and broken grains than in cleaner parcels. The pupal stage, during which change to the adult takes place, occurs inside the grain for the grain weevil and inside gelatinous cocoons in the germ or between the grains for the other beetles. The holes in grain are caused by the adult weevil boring its way out and show that at least one generation has been produced. The other beetles are usually only noticed when their numbers have become so great that they cause heating or when they start crawling out of the grain. The adult grain weevil is about $\frac{3}{8}$ in. long, black, with a distinct snout; the saw-toothed grain beetle is about $\frac{1}{2}$ in. long, dark brown, and has serrations along the side of the front part of the body; the rust red grain beetle is about $\frac{3}{16}$ in. long, reddish brown, with long feelers. They all live for about nine months (Plate VIII).

The beetles and mites are all resistant to cold and can survive the winter in unheated granaries. There is however a minimum temperature, different for each species, below which complete development from egg to adult cannot take place. For the grain weevil this temperature is about $55^\circ \text{F}$ (although development is slow even at $63^\circ \text{F}$) and for the saw-toothed grain beetle about $68^\circ \text{F}$. As the temperature rises the insects develop more quickly, and there is an optimum combination of temperature and grain moisture content at which the cycle from egg to adult is completed in the shortest time,
or the number of insects increases at the fastest rate. For the saw-toothed grain beetle the life cycle is from 80 days at 68°F to only 20 days at 90-95°F and moisture content of 14-22 per cent. At the higher temperatures the population may increase 50-100 fold in a month.

It has been calculated that, if a 50 ton lot of grain goes into store at 95°F (which it may well do if it has not been cooled after drying) and its temperature remains over 77°F for three months, then as few as 500 saw-toothed grain beetles originally present could multiply to 5 million, prevent further cooling and cause the grain to heat.

In grain of 14 per cent moisture content the grain weevil takes from 180 days at 60°F to 26 days at 86°F. Heating can be induced by only two fully grown weevil grubs per 1 lb of wheat.

Beetles and mites cannot breed in very dry grain (9 per cent m.c. or less) but do well at the usual moisture content (14 per cent upwards) of farm stored grain.

The young of the flour mite are like the adults (about 1/8 in. long) except that they are smaller and cannot breed. Mites attack the germ and breed between 40°F and 90°F. The life cycle takes from five months at the lower temperature to fourteen days at about 70°F, provided the grain is over 14 per cent m.c.

Insects and mites are carried to farms in various ways, the principal being on animal feeding-stuffs, especially unprocessed imported cereals, cereal products and oilcakes; on grain from other farms and on sacks, especially second-hand sacks which have not been properly cleaned and disinfested. Hired sacks, which have not been through a central cleaning depot betweenhirings, may also be a source of trouble.

**PRECAUTIONS BEFORE STORAGE**

**Pre-harvest Preparation, Structural Methods and Hygiene**

Thorough cleanliness, by removing spillage in which insects can breed and survive between harvests, is the principal measure for preventing infestation. It follows that the grain store should be constructed with smooth surfaces and without cracks, crevices, dead spaces and places difficult to clean. If such spaces are necessary, because of the type of storage adopted (e.g., various types of underfloor ventilation) the farmer must either recognize that if an insect outbreak occurs major structural work might be necessary to eradicate the insects, or arrange for the plant to be designed initially in a manner which enables cleaning to be done without undue difficulty, even if this raises the initial capital cost.

Machinery should be properly constructed and empty sacks not used to repair holes in floors or to cover joints in trunking. Sacks used for carriage of grain, even from combine to store, should be free from insects and mites, kept in a separate rat proof store, and be fumigated if there is any suspicion of infestation.

Since it is important that grain should be kept dry and cool, horizontal and cascade driers should not be operated without a canopy in the same building that houses grain, and the exhausts of other types of driers should
CONTROL OF PESTS

discharge to the outside air. Chaff and weeds removed from grain in course of cleaning and drying should be finely ground and used in feeds or destroyed by burning, burying or composting. Neither screenings nor animal feeds should be kept in the grain store, which should be reserved entirely for grain produced on the farm.

INSECTICIDES

Shortly before intake of the new harvest the grain store should be thoroughly cleaned and treated with a suitable insecticide, applied as spray, dust or smoke.

The two most useful insecticides are malathion and lindane, the former being somewhat more persistent. Both should be applied as water dispersible sprays, so that insecticide is not lost by soaking into porous surfaces. Emulsions may be used on metal bins. Malathion should be used at a strength of 1.5 per cent, one gallon of made-up spray being applied to 1,000 sq. ft of surface; such a deposit is effective for 2–3 months. 0.5 per cent lindane, applied at the same rate, lasts about 4–6 weeks.

The insecticides are most conveniently applied by a pneumatic knapsack sprayer with a fan spray nozzle. The aim should be to spray the surface only until the liquid begins to run off. All bins should be sprayed, inside and out together with walls, floors and undersides of the roof. Conveyors and elevator boots may be sprayed or dusted (2 per cent malathion dust) or treated with smoke insecticides. Those containing DDT or lindane or both, are convenient for use in air passages in drying plants or ventilated floor storages. They should be used at the rate recommended by the manufacturer for crawling insects. It should be stressed that treatment with smoke does not have the same effect as fumigation with gas, since smoke settles on surfaces to leave an insecticidal film and does not penetrate.

PRECAUTIONS DURING STORAGE

During storage all grain should be inspected frequently. Grain temperatures should be recorded and, if the grain starts to heat, the moisture content should be checked and, if this is at a safe level, insects should be searched for, using a sampling spear for bulk grain. Grain should not be turned or moved until the cause of the heating has been verified, since disturbance may cause the insects to spread throughout the building and make eventual control more difficult.

Cooling

Storing grain at a low temperature is the surest method of preventing or delaying insect attack. The cooling sections of driers should be properly used. The object is to reduce temperature to below 63°F and preferably to below 55°F as soon as possible, so as to render grain safe from attack by the saw-toothed grain beetle and the grain weevil. Methods of cooling grain in store are described in Cooling Grain to maintain its Condition.

Addition of Insecticide to Grain

Mixing insecticides with grain is a useful preventive measure. In particular,
the addition of malathion to provide 8–10 parts per million in grain which is cool and dry may prevent development of insect infestation for a period of six months. The malathion may be added as a powder or emulsion spray in a manner which ensures even distribution. This method is not recommended for ventilated storage because malathion breaks down quickly in contact with damp grain and blowing warm air through the grain accelerates normal breakdown of the insecticide. Malathion should not be mixed with malting barley unless it has been ascertained that the maltster does not object.

**CONTROL**

If stored grain becomes infested the two main control measures are cooling or fumigation.

**Cooling**

The latter is practicable in ventilated bins or floor stores since this does not involve disturbance of the grain. If infested grain has to be turned or passed through a drier for cooling the disturbance may cause insects to spread. Such movement should therefore only be done in cold weather and the empty bin, conveying system and the surroundings must be treated with insecticide.

**Fumigation**

Fumigation is treatment with a gas, which may be applied in that form or as a liquid or tablet.

Grain stored in silos, including ventilated bin driers and that stored on floors, can be fumigated, dependent on the gastightness of the bins or bulk-heads. The extent and nature of the treatment necessary has to be determined in each case, taking into account the time of year, the construction of the store, the quantity of grain, the degree and distribution of the infestation, the condition of the grain (whether caked or damp) and the period of time for which it is to be stored after treatment.

Fumigation is most likely to be satisfactory if the grain surface is level, so that the fumigant penetrates evenly into the grain. The treatment of heaped up bulk grain is less satisfactory even when liquid fumigant can be applied without the operator needing to walk on the grain. Tablet fumigants cannot be applied to heaped up grain without considerable disturbance and spillage.

Fumigation of the grain itself needs to be supplemented by spraying, with contact insecticide, the structure of the grain store to kill insects outside the fumigation area.

**Liquid Fumigants**

Grain in bulk can be treated with liquid fumigants poured or pumped onto the surface. For grain more than 8 ft deep a 1:1 mixture of ethylene dichloride and carbon tetrachloride should be used, sprinkled evenly over the surface at the rate of 1 gallon for 5 tons grain. The surface should be covered with rick sheets or sacks to protect it from draughts and left undisturbed for a week. All spouts and trunking leading to ventilated bins should be carefully
CONTR01. OF PESTS

blocked off to prevent loss of fumigant. Grain less than 8 ft deep may be treated in similar fashion, but a higher proportion of ethylene dichloride is desirable and a 3 : 1 mixture should be used.

The 3 : 1 mixture may be used for grain in bags. The bags may be placed in metal containers having well fitting lids e.g., dustbins, or may be wrapped in gas proof sheets. In either case the rate of application should be 5 pints per ton for a period of exposure of at least 48 hours. For empty sacks the dosage should be 2 pints per cwt for 48 hours or 1½ for 72 hours.

The grain should be well aired before it is moved or before anyone enters a bin.

Tablet Fumigants

Another method of fumigation is the addition of tablets of aluminium phosphide to the grain. These can be put into bagged grain by hand or inserted into bulk grain with special applicators. The material reacts with moisture in the air to produce phosphine gas. The tablets are used at the rate of 10-15 per ton in small bins and 15-20 per ton for floor stored grain. Treatment at temperatures below 50°F is not recommended. Grain in sacks can be treated at the rate of 2-3 tablets per sack.

The standard period of treatment is five days but grain should be aired for a further seven days before it is moved.

Precautions

It will be appreciated that fumigation is difficult and dangerous unless carried out very carefully. For these reasons fumigations, except of small quantities of grain or empty sacks, should be done by pest control servicing firms.

PROOFING BUILDINGS

Existing and new buildings should be proofed as far as possible against entry by rats, mice, insects and birds.

Holes

Holes in brick, stone or concrete floors, if in excess of ½ in. should be filled. Small holes should be filled with a mortar composed of 4 parts of sand to 1 part of cement and larger holes with a fine concrete mix of 4 parts ⅜ in. aggregate, 2 parts sand and 1 part cement with broken glass mixed in to prevent reopening during setting.

All brick and concrete surfaces should be as smooth as possible to prevent insect harbourage, and for that reason even very small holes should be filled in. The points of entry of electric cables and gas or water pipes should be examined and made good if necessary. The points of entry of overhead cables at eaves should be examined and any openings filled in.

Roofs

Roofs should be sound. The eaves should be examined to ensure that the walls are carried up to the underside of the roof covering to prevent entry by mice and birds.
Doors
For making sliding doors rodent-proof, a lift-out screen can be fitted on the face of the wall that is free from the sliding-door gear. Worn steps and thresholds must be made up level to close any gaps beneath the door. In some cases it is possible to insert in the threshold an iron bar projecting half an inch on to which the door can close.

If it is essential that doors are kept open during the day or night, a screen should be provided to fill the opening completely. This should be of light timber covered with \( \frac{1}{4} \) in. galvanized expanded metal. It will also keep out birds.

Windows
Windows should be examined and any broken glass renewed. Holes in the frame or sashes should be filled in, and, if it is necessary to keep windows open or to have squares permanently open for ventilation, these should be protected by screens of not more than \( \frac{1}{4} \) in. mesh.

Air Bricks, Ventilators and Other Openings in Walls
Where any such openings in walls are larger than \( \frac{1}{4} \) in. they should be protected by screens of not more than \( \frac{1}{4} \) in. mesh.

Holes in walls for drain channel outlets should be proofed with perforated metal grids which should be removable for cleaning.

External Down-pipes and Poles Near Buildings
These should be fitted with cone-shaped guards projecting 9 in. from the pipe or pole and fitted with a collar and metal strap which can be tightened to give a close fixing. Cone-shaped guards should be fitted tightly to the brickwork.

Drains
If rats are suspected in the drains a poison treatment should be carried out and all drainage and sanitary fittings examined and repaired where necessary. The more usual defects are broken manhole covers, fresh-air inlets, defective pipes and dried-out or broken W.C. pans, all of which will allow rats to leave the drains and enter the building.

Internal Harbourages
Any hidden or inaccessible spaces should be reduced to a minimum, e.g., where possible, floors constructed with timber joists should not have ceilings below. Hollow timber stud partitions are undesirable. Cracks and expansion joints in concrete floors should be filled, as these form harbourage for insects and mites and allow grain to accumulate.

New Buildings
Where new buildings are to be constructed, care should be taken to ensure that all disused drains are dug out and the site made up with hardcore.
drains should be carefully diverted from the site, with the dual objects of draining the foundations and avoiding harbourage for rats.

**Bird Proofing**

Every effort should be made to keep birds out of buildings used for the storage and drying of grain, as they not only foul the contents with their droppings but tend to nest in any convenient part of the roof, such as the eaves and on and around the trusses and other roof members.

Bird-nesting material, often containing weed seeds, not only provides food for mice but can encourage the development of an infestation of insects and mites if any are present.

Normally ½ in. hexagonal galvanized wire netting will keep birds out, but they will fly through quite small holes and even up the corrugation of vertical asbestos-cement or iron sheeting where this overlaps the wall in such places as gable ends.

Holes should be plugged with concrete or mortar unless they occur in asbestos cement or iron roof sheeting, when a plastic filler may be used or in some cases crumpled up wire netting forced in tightly. Corrugated sheets overlapping a wall can be proofed with concrete on the inside laid on top of the wall and into the corrugations.

Buildings constructed with corrugated asbestos cement or iron roofs and sides may be proofed at the eaves with hexagonal wire netting rolled up tightly and forced into the space between the vertical and sloping sheeting.

To prevent birds from flying through open doorways, black nylon net screens can be used, if it is impracticable to keep the doors closed, but as this material is easily damaged it should be fixed into light timber frames arranged to open easily or to be removed entirely.

Birds have been known to peck out soft fillers such as fibre-glass, foam slag or plastic materials and these should not be used.

**Maintenance**

It is extremely important that grain drying and storage buildings be kept scrupulously clean and no grain should be allowed to accumulate, thereby attracting rats, mice and insects. Silos and the whole of the drying plant should be cleaned out regularly, the former whenever they are empty and the latter before and after harvest.

Undergrowth around buildings should be kept down and trees and projecting branches, from which rats could jump to the roofs of buildings, should be felled or lopped respectively.

Accumulations of rubbish, timber or other unwanted debris around buildings all provide harbourage for rats and should be cleared away.

**Advice and Assistance**

For advice on any aspect of control of insects and mites in stored grain farmers may apply to the District Advisory Officer of the National Agricultural Advisory Service, and in respect of rats, mice and birds to any Divisional Office of the Ministry; or, in respect of all kinds of pests to the Regional Pests Officer at any of the Ministry's Regional Offices.
In Scotland, the Department of Agriculture and Fisheries for Scotland is responsible and further advice may be obtained from any of the Department’s Infestation Control offices (Glasgow, Edinburgh and Perth) or from the Agricultural Scientific Services, Last Craigs, Edinburgh 12.
APPENDIX I

Safety Regulations

Attention is drawn to Regulations made under the Agriculture (Safety, Health and Welfare Provisions) Act, 1956, which affect some of the buildings, plant and machinery dealt with in the Bulletin. The main regulations that apply are:

The Agriculture (Safeguarding of Workplaces) Regulations 1959 which require certain safety standards in places where farm workers are employed. In general, stairs and floors must be as safe as is reasonably practicable for the purposes for which they are used. Detailed requirements include the provision of handrails or handholds for stairs and the fencing of openings through or from which a worker might fall more than 5 ft.

The Agriculture (Stationary Machinery) Regulations 1959 which require the components of stationary machines used by farmworkers to be guarded, unless they are so positioned that the worker is safe against contact. The regulations also require the provision of stopping devices and there must be adequate lighting where a machine is used.

The Agriculture (Field Machinery) Regulations 1962 require field machines, such as combines, pick-up balers, etc., to be guarded so as to protect farm workers from contact with their dangerous parts. Other safety requirements include the provision of stopping devices, draw bar jacks, standing platforms and seats and footrests.

The Agriculture (Lifting of Heavy Weights) Regulations, 1959 which are effective from 1st July 1965, state that the maximum weight of a sack or bag and its contents which a worker employed in agriculture may lift or carry, unaided, is 180 lb.

Full details of these Regulations are given in the booklet 'Farm Safety: Guide to the Safety, Health and Welfare Act and Regulations' a copy of which has been sent to every farmer. Copies can be obtained from any divisional office of the Ministry.
APPENDIX II
Useful Data and Tables

1. Metric Conversion Factors

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<th>For converse multiply by</th>
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2. Temperature Conversion

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164
The formulae for converting Centigrade and Fahrenheit temperature are as follows:

\[
\text{Temp. C} = \frac{5(F - 32)}{9} \quad \text{Temp. F} = \frac{9}{5}C + 32
\]

For temp. rise or fall calculations:

\[
\text{Temp. change C} = F \times \frac{5}{9} \quad \text{Temp. change F} = C \times \frac{9}{5}
\]

3. Units and their Equivalent

Volume

1 cu. ft = 0.78 bushel
1 bushel = 1.285 cu. ft

Weight

1 cwt = 112 lb
1 lb = 7,000 grains

Pressure

1 in. water gauge = 0.036 lb/sq. in. = 5.194 lb/sq. ft
1 lb/sq. in. = 27.71 in. of water = 2.04 in. mercury

Power and Energy

1 h.p. = 746 watt
= 42.4 B.t.u./min
1 kilowatt = 1,000 watt
= 56.9 B.t.u./min
1 kilowatt hour = 3,412 B.t.u.

4. Heat

**Table A3**

Calorific values of commonly used heat sources in grain drying

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<thead>
<tr>
<th>Heat source</th>
<th>Calorific value B.t.u.‡</th>
<th>Unit of measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gross</td>
<td>net</td>
</tr>
<tr>
<td>Diesel or gas oil</td>
<td>166,000</td>
<td>156,000</td>
</tr>
<tr>
<td>Coal gas</td>
<td>500*</td>
<td>459</td>
</tr>
<tr>
<td>Propane</td>
<td>21,500</td>
<td>19,800</td>
</tr>
<tr>
<td>Butane</td>
<td>21,300</td>
<td>19,600</td>
</tr>
</tbody>
</table>

* On this basis 200 cu. ft = 1 therm = 100,000 B.t.u.
‡ See p. 98 for further information on calorific values of fuel.
5. **Moisture Content**

Moisture content of grain or other material may be expressed in either of two ways:

- **a. wet weight basis** = \( \frac{\text{weight of moisture present}}{\text{weight of undried matter}} \times 100\% \)

- **b. dry weight basis** = \( \frac{\text{weight of moisture present}}{\text{weight of dry stock}} \times 100\% \)

Method (a) is the one normally employed in commercial practice.

To convert from moisture content from a wet weight basis \( (M_W) \) to a dry weight basis \( (M_D) \):

\[
M_D = \frac{100 \times M_W}{100 - M_W}
\]

and to convert from a dry weight basis \( (M_D) \) to a wet weight basis \( (M_W) \):

\[
M_W = \frac{100 \times M_D}{100 + M_D}
\]

To calculate loss, multiply the original weight of grain by the factor found at the intersection of the two columns—Initial moisture content and Final moisture content.

**Example:**

28 ton of grain at 24% m.c. dried to 14%

= 28 ton \( \times 1.163 = 3256.4 - 3 \) ton 5 cwt 14 lb loss of weight.

Formulae for calculations not covered by Table A5.
For use where undried weight is known

\[
\text{Loss in weight} = \frac{W_1(M_1 - M_2)}{100 - M_2}
\]

where

\[W_1 = \text{weight of undried grain}\]

### Table A5

<table>
<thead>
<tr>
<th>Initial moisture content per cent</th>
<th>Final moisture content per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>27</td>
<td>0.988</td>
</tr>
<tr>
<td>26</td>
<td>0.865</td>
</tr>
<tr>
<td>25</td>
<td>0.741</td>
</tr>
<tr>
<td>24</td>
<td>0.618</td>
</tr>
<tr>
<td>23</td>
<td>0.494</td>
</tr>
<tr>
<td>22</td>
<td>0.371</td>
</tr>
<tr>
<td>21</td>
<td>0.247</td>
</tr>
<tr>
<td>20</td>
<td>0.124</td>
</tr>
<tr>
<td>19</td>
<td>0.122</td>
</tr>
<tr>
<td>18</td>
<td>0.121</td>
</tr>
<tr>
<td>17</td>
<td>0.120</td>
</tr>
<tr>
<td>16</td>
<td>0.117</td>
</tr>
</tbody>
</table>

* Some loss of dry matter may occur during drying, particularly if the grain is dirty, so that losses in practice may be slightly higher than indicated here.

For use where dried weight is known

\[
\text{Loss in weight} = \frac{W_2(M_1 - M_2)}{100 - M_2}
\]

where

\[W_2 = \text{weight of dried grain}\]

### Platform Driers (moisture extraction rate)

To check the percentage of moisture extracted from a sack of grain:

\[
\frac{100(x - y)}{x} = \% \text{ moisture extracted}
\]

where \(x\) = the weight in lb of the grain before drying commences,

\(y\) = the weight in lb of the grain after a period of drying

### Grain wetting

Quantity of water to be added (assuming all is absorbed) to give a moisture content of 18 per cent.

For conditions other than those given in Table A5, the following formula may be used:

\[
\text{Water to be added (gal)} = \frac{224 \times W_2(M_1 - M_2)}{(100 - M_2)}
\]

where

\[W_2 = \text{weight of dried grain}\]

\[M_1 = \text{m.c. of undried grain}\]

\[M_2 = \text{m.c. of dried grain}\]
## APPENDIX II

### TABLE A6

*Gallons of water per ton of dry grain to wet to 18 per cent m.c.*

<table>
<thead>
<tr>
<th>Initial grain m.c. per cent</th>
<th>Gallons per ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>10.9</td>
</tr>
<tr>
<td>15</td>
<td>8.2</td>
</tr>
<tr>
<td>16</td>
<td>5.5</td>
</tr>
<tr>
<td>17</td>
<td>2.7</td>
</tr>
</tbody>
</table>

### 6. Storage Buildings

### TABLE A7

*Weights and measures*

<table>
<thead>
<tr>
<th>Crop</th>
<th>Weight per cu. ft (lb)</th>
<th>Weight per bushel (lb)</th>
<th>Cu. ft per ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>49</td>
<td>63</td>
<td>46</td>
</tr>
<tr>
<td>Barley</td>
<td>43</td>
<td>56</td>
<td>51</td>
</tr>
<tr>
<td>Oats</td>
<td>32</td>
<td>42</td>
<td>70</td>
</tr>
<tr>
<td>Rye</td>
<td>44</td>
<td>57</td>
<td>51</td>
</tr>
<tr>
<td>Peas</td>
<td>48</td>
<td>63</td>
<td>46</td>
</tr>
<tr>
<td>Beans</td>
<td>51</td>
<td>66</td>
<td>43</td>
</tr>
<tr>
<td>Linseed</td>
<td>41</td>
<td>54</td>
<td>51</td>
</tr>
</tbody>
</table>

*Notes: Column No. 3 is based on average figures*  
1 bushel = 1.285 cu. ft

### TABLE A8

*Capacities for cylindrical bins*

<table>
<thead>
<tr>
<th>Dia. (ft)</th>
<th>Cu. ft</th>
<th>Wheat (tons)</th>
<th>Barley (tons)</th>
<th>Oats (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>50</td>
<td>1.1</td>
<td>1.0</td>
<td>0.75</td>
</tr>
<tr>
<td>9</td>
<td>64</td>
<td>1.4</td>
<td>1.25</td>
<td>0.9</td>
</tr>
<tr>
<td>10</td>
<td>79</td>
<td>1.7</td>
<td>1.55</td>
<td>1.5</td>
</tr>
<tr>
<td>11</td>
<td>95</td>
<td>2.1</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>12</td>
<td>113</td>
<td>2.45</td>
<td>2.2</td>
<td>2.25</td>
</tr>
<tr>
<td>13</td>
<td>133</td>
<td>2.9</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>14</td>
<td>154</td>
<td>3.35</td>
<td>3.0</td>
<td>2.25</td>
</tr>
<tr>
<td>15</td>
<td>177</td>
<td>3.85</td>
<td>3.5</td>
<td>2.6</td>
</tr>
</tbody>
</table>
# APPENDIX II

## Table A9

**Pressures on retaining walls**

*Rankine’s Formula*

Pressures for surcharged walls are for grain heaped at the angle of natural repose over the level heap to same height

<table>
<thead>
<tr>
<th>h (feet)</th>
<th>fy (lb)</th>
<th>Fy (lb)</th>
<th>Fy (lb)</th>
<th>Fy (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>53</td>
<td>106</td>
<td>159</td>
<td>320</td>
</tr>
<tr>
<td>5</td>
<td>66</td>
<td>164</td>
<td>199</td>
<td>501</td>
</tr>
<tr>
<td>6</td>
<td>79</td>
<td>236</td>
<td>239</td>
<td>715</td>
</tr>
<tr>
<td>7</td>
<td>63</td>
<td>312</td>
<td>279</td>
<td>978</td>
</tr>
<tr>
<td>8</td>
<td>105</td>
<td>431</td>
<td>318</td>
<td>1,271</td>
</tr>
</tbody>
</table>

Notes: h = height of vertical retaining wall  
fy = horizontal thrust  
Fy = horizontal pressure per ft run 1/4 height of wall  
Density of grain 49 lb per cu. ft  
Angle of repose 35°

## Table A10

**Safe bearing pressure of various soils**

<table>
<thead>
<tr>
<th>Description of soil</th>
<th>Approx. safe maximum load in tons per sq. ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marshland, silt, mud, hard peat, turf</td>
<td>0 - 0.20</td>
</tr>
<tr>
<td>Marshclay, alluvial deposits</td>
<td>0.20 - 0.35</td>
</tr>
<tr>
<td>Alluvial earth, clay loam, damp clay, loam</td>
<td>0.50 - 1.00</td>
</tr>
<tr>
<td>Soft chalk, soft sandstone</td>
<td>1.00 - 1.50</td>
</tr>
<tr>
<td>Loose sand</td>
<td>2.00 - 3.00</td>
</tr>
<tr>
<td>Hard white chalk</td>
<td>3.00 - 4.00</td>
</tr>
<tr>
<td>Firm clean sand</td>
<td>5.00 - 6.00</td>
</tr>
<tr>
<td>Firm shale, compact gravel</td>
<td>6.00 - 8.00</td>
</tr>
<tr>
<td>Hard rock</td>
<td>8.00 - 12.00</td>
</tr>
</tbody>
</table>
## Appendix II

### Table A11

*Loading imposed by grain on floor (assuming no load taken by walls)*

<table>
<thead>
<tr>
<th>Height (ft)</th>
<th>Load (lb/sq. ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>98</td>
</tr>
<tr>
<td>3</td>
<td>147</td>
</tr>
<tr>
<td>4</td>
<td>196</td>
</tr>
<tr>
<td>5</td>
<td>245</td>
</tr>
<tr>
<td>6</td>
<td>294</td>
</tr>
</tbody>
</table>

Grain in sack (wheat) (1 sack, 4-bushel, weighs 252 lb and covers an area of 3 sq. ft)

<table>
<thead>
<tr>
<th>Number of Sacks</th>
<th>Load (lb/sq. ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>81</td>
</tr>
<tr>
<td>2</td>
<td>168</td>
</tr>
<tr>
<td>3</td>
<td>252</td>
</tr>
</tbody>
</table>

### Table A12

*Rolled Steel Joists*

*Safe loads for mild steel. Based on BS 449 (amended 1964)*

<table>
<thead>
<tr>
<th>Size D x B inches</th>
<th>Wt per ft</th>
<th>Safe Distributed Loads in tons for spans in feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>8 x 4</td>
<td>17</td>
<td>12.1</td>
</tr>
<tr>
<td>7 x 4</td>
<td>16.5</td>
<td>9.1</td>
</tr>
<tr>
<td>6 x 3½</td>
<td>14.5</td>
<td>6.1</td>
</tr>
<tr>
<td>5 x 3</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>4 x 2½</td>
<td>11</td>
<td>6.5</td>
</tr>
<tr>
<td>3 x 2</td>
<td>4.5</td>
<td>4</td>
</tr>
</tbody>
</table>

*Loads to right of zigzag line give deflection exceeding \( \frac{1}{360} \)th span.*

### Table A13

*Universal Steel Beams*

*Safe loads for mild steel. Based on BS 449 (amended 1964)*

<table>
<thead>
<tr>
<th>Size D x B inches</th>
<th>Wt per ft</th>
<th>Safe distributed loads in tons for spans in feet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>12 x 6½</td>
<td>36</td>
<td>26.8</td>
</tr>
<tr>
<td>11</td>
<td>31</td>
<td>23.0</td>
</tr>
<tr>
<td>10 x 5½</td>
<td>29</td>
<td>19.9</td>
</tr>
<tr>
<td>9</td>
<td>27</td>
<td>18.8</td>
</tr>
<tr>
<td>8 x 5½</td>
<td>25</td>
<td>17.8</td>
</tr>
<tr>
<td>7</td>
<td>21</td>
<td>16.8</td>
</tr>
<tr>
<td>6 x 3½</td>
<td>20</td>
<td>15.8</td>
</tr>
<tr>
<td>5 x 3</td>
<td>17</td>
<td>14.8</td>
</tr>
</tbody>
</table>

*Loads to right of zigzag line give deflection exceeding \( \frac{1}{360} \)th span.*
References


REFERENCES


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