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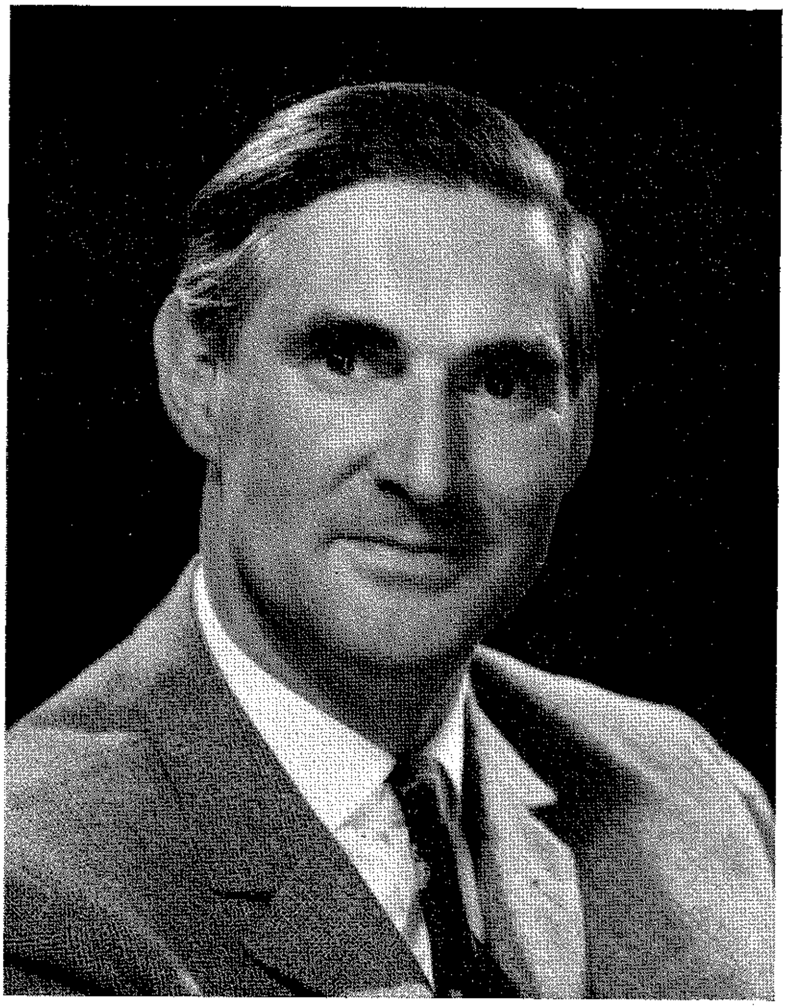
THE PRESIDENT



Mr J. H. W. WILDER

At the Annual General Meeting of the Institition held on 22 April 1965, Mr J. H. W. Wilder, BA(CANTAB), MI AGR E, was elected President for 1965-66.

Mr Wilder, who was elected a member of the Institution in 1948, served on Council from 1954-57, 1958-59 (as a Vice-President) and became President-Elect in 1963. He has twice fulfilled a term as Chairman of the Membership Committee.

Mr Wilder, a Director of John Wilder Ltd, comes from a long-established family firm of agricultural engineers. His earlier experience includes a lectureship at the Military College of Science and nearly two years in West Africa in charge of tropical tests on army equipment, during which time he held the rank of Major. Currently he is Vice-Chairman of the Governing Body of the National Institute of Agricultural Engineering, Chairman of the Agricultural Machinery Industry Standards Committee of the British Standards Institution and serves on the Council of his native town of Wallingford.

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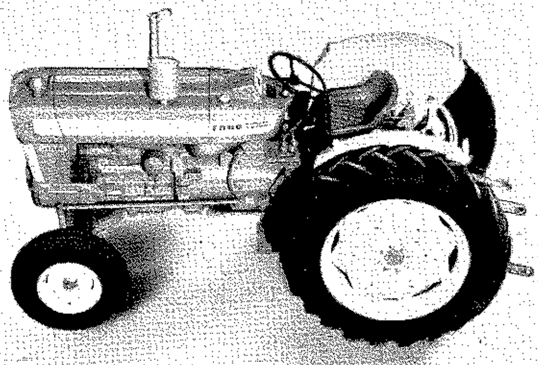


1965–The year of the all-new Fords

INSTITUTION NOTES

Extraordinary General Meeting

An Extraordinary General Meeting of the Institution was held in London on 22 April 1965. Over a hundred amendments to the Articles of Association were approved; among them were changes to the constitution of the Council. The office of President-Elect, hitherto not covered by the Articles, is now included among the appointments subject to nomination and election. The number of Past Presidents serving at any one time on the Council may henceforth not exceed eight in number and will be subject to nomination and election (except in the case of the Immediate Past President who will, *ex officio*, be one of the eight). It is now possible for a Graduate to be elected to the Council; previously he could only be co-opted with limited powers.

The qualifications for the various grades of membership have been amended. The liability to satisfy an examination requirement is now expressly stated in connection with election or transfer to Corporate Membership. The qualifications for Graduate and Student membership have likewise been reworded to link them more closely to the Institution's revised examination structure which comes into full effect in 1966. The upper age limit of 28 years, after which a person could not be elected a Graduate or remain any longer as a Student, has been abolished. The minimum age limits remain at 21 and 17 years respectively but the maximum period that any person may remain in Graduate or Student Membership is 10 and 7 years respectively. The designatory letters to be used by Graduates and Students have been amended, as announced elsewhere in this issue of the *Journal*.

The administrative structure of the Examination Board in Agricultural Engineering has been strengthened by the introduction of an Article granting constitutional authority for the appointment of Board Secretary. Other amendments have been made to ensure that the Board's control of the National Diploma in Agricultural Engineering and other examinations for which the Institution is responsible is adequately safeguarded.

A great many of the amendments were of a minor nature in themselves but collectively they represent a thorough overhaul of the Institution's administrative foundation, so that the affairs of the Institution may be conducted in a modern and progressive manner.

The Meeting approved proposals to amend the scale of Entrance Fees and Transfer Fees, and the annual subscription differential applicable to Graduates under 27 and Students over 24 years of age was abolished. The new scale is published in full on page 82 of this issue of the *Journal*.

Annual General Meeting

The aforesaid Extraordinary General Meeting was immediately followed by the Annual General Meeting of the Institution. After the Minutes of the 1964 AGM had been approved, the President (Mr W. J. Priest, MI AGR E) moved the adoption of the Annual Council Report for 1964. He drew attention to the salient features of the year's work and emphasized the important achievements of the Examination Board, Education Committee and Membership Committee.

The President paid tribute to the work of the eight Branches and said there was every hope that a new Branch north of London would be formed in the light of evidence suggesting strong support for it. Part of the object of holding an Open Meeting in Silsoe during the autumn of 1965 was to test the response of members to the idea of holding meetings in that vicinity. Mr Priest went on to draw attention to the major reorganization of the Institution's administration that had taken place during 1964, as reflected by the changes in the Articles of Association and by the substantial re-equipment of the Institution offices currently in progress.

The President said it gave him keen satisfaction as he drew to the close of his term of office to announce that Council had conferred Honorary Membership upon Mr D. R. Bomford, a Past President of the Institution. Having regard to the distinguished contribution Mr Bomford had made to agricultural engineering over many years, the Council had been of one accord in wishing to confer the highest honour within the Institution's power to bestow. A Certificate of Honorary Membership, together with a Citation, would be presented to Mr Bomford at the Open Meeting in Silsoe in September 1965.

Finally, Mr Priest commended the Secretary, Assistant Secretary and other staff for their assistance during his Presidency.

The Hon. Treasurer, Mr R. C. Dick, presented the Accounts of the Institution for 1964. He said the year had been one in which a number of measures had been taken to strengthen and equip the Institution for its growing responsibilities. This had necessarily entailed considerable expenditure, notably in examination administration and office re-organization. On the other hand, income had benefitted from the collection of certain long overdue subscriptions. He felt that the modest excess of expenditure over income of £225 was an acceptable penalty.

Nominat ions to fill vacancies among Officers and Ordinary Members of the Council for the year 1965-66were confirmed. The complete list of the New Council appears on p 47 of this issue of the *Journal*.

Gimson & Co, Chartered Accountants, of Charterhouse London E.C.1 were appointed Auditors to the Institution for 1965.

Annual Conference

'Grain Conservation' was the theme of the Institution's highly successful Annual Conference in London on 22 April. Over 120 members and others were present to hear the four Papers and Discussions. The full texts of the lectures, together with a report of the discussions provide the main content of this issue of the *Journal*.

Annual Dinner

Also in this issue, there appears a report of the principal speeches at the Institution's Annual Dinner. This function took place in St Ermin's Hotel, London, on 22 April. Guests of Honour included the Rt. Hon. Earl de la Warr, PC, GBE and Professor A. W. Scott, CBE, BSC, PHD, MI MECH E. The latter is Professor of Chemical Engineering at the University of Strathclyde.

Future Institutional Activities

In London, and throughout the country, the Council and the eight Branch Committees are planning the Institution's programme of lectures, outings and social functions for the 1965-66 winter session. Full details will be circulated to all members during the early autumn and announcements will appear in the *Journal* and the press from time to time.

In south-east England, the pattern of activity is being reshaped so that meetings will tend to orbit flexibly around London rather than be held invariably at the city centre. Instead of holding Open Meetings in London during October and January, an all-day Open Meeting is to be held in the National College of Agricultural Engineering, Silsoe, Bedford on 28 September 1965 and attempts are to be made to organize a further all-day Open Meeting in Kent during March 1966. The Annual Conference and Annual Dinner will continue to be held in London.

Forthcoming Conferences and Exhibitions

Engineering Inspection in the Future

The annual National Inspection Conference, organized by the Institution of Engineering Inspection is to be held at New College, Oxford, during the period 20-23 September 1965. Registration forms may be obtained from the Institution of Engineering Inspection (Oxford Conference), 616 Grand Buildings, Trafalgar Square, LondonW.C.2.

International Work Meeting on Farm Labour

Organized jointly by Commission Internationale du Génie Rural (CIGR), Section V, and the Internationaler Ring für Landarbeit (IRL—CIOSTA), this Work Meeting will be held at the 'Kurhaus' Bad Kreuznach, during the period 23-25 November 1965. Papers and discussions will deal with both out-door and in-door work and the labour situation in different countries. Registration forms may be obtained from Studiengesellschaft für Landwirtschaftliche, Arbeitswirtschaft E.V., 6550 Bad Kreuznach, W. Germany.

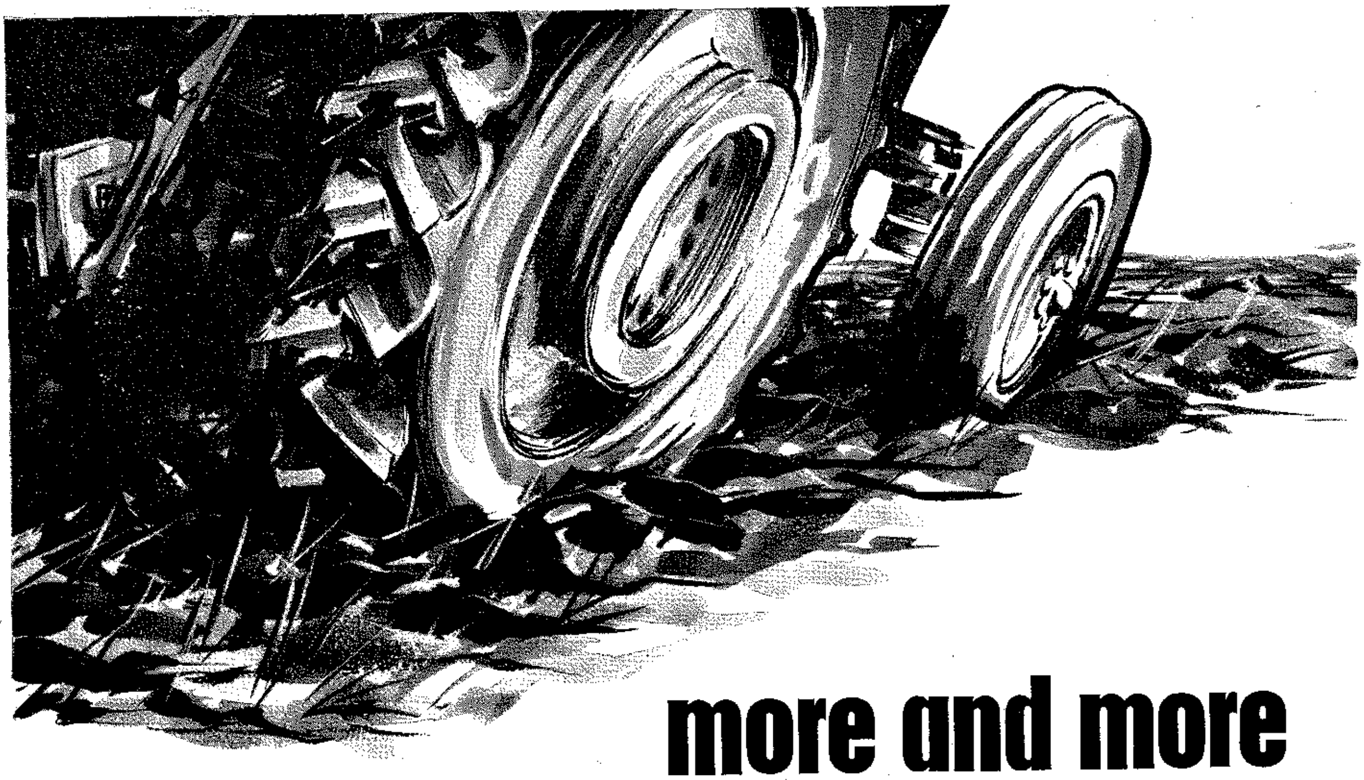
CIGR Section II Seminar on Farm Structures

This event, which will be held at Churchill College, Cambridge during the period 20-24 September 1965, takes the place this year of the *Farmers Weekly* National Farm Buildings Conference. It is being organized by Farm Journals Ltd under the aegis of an *ad hoc* committee convened for the purpose by the Institution. Represented on the Committee are the Electricity Council, the Electrical Department Association, the FarmBuildings Association, the Farm Buildings Centre and the Ministry of Agriculture, Fisheries and Food.

The themes of the Seminar will include buildings for sows, modern grain storage structures and the development of modular co-ordination in the farm building sphere; there are also a number of miscellaneous papers. Three dozen papers have been offered by scientists and advisors representing most European countries, including some from Eastern Europe and from the USA and Canada.

Prior to the Seminar a number of farm tours are to be organized; these are expected to commence on 15 September.

Full details and application forms can be obtained from Farm Journals Ltd, Room 518, 161/166 Fleet Street, London E.C.4.



PUBLICATIONS AND REVIEWS

Biochemical Engineering
by F. C. Webb:
Van Nostrand;
1964; 120*s*.

This book is obviously destined to become a standard textbook for students of chemical and biochemical engineering. It should also be a standard reference book for anyone concerned with the development or design of mechanical plant used for processing biological materials. Many sections are of direct importance to agricultural engineers, such as those on reduced temperature preservation of fruit and vegetables, grain drying and radiation heating. Although the chapters on vaccine manufacture or on proteins and enzymes are outside the present interests of agricultural engineers, the chapter on equipment design alone makes the book worth reading. The reviewer has never before read a book which has so crystallized and defined his own half-formed ideas and concepts. The abiding impression is that Dr Webb has done more than bring together many widely varying topics and build them into an authoritative, comprehensive, well-illustrated and readable textbook. He has mapped out and has produced the foundation for a new, coherent discipline. K.E.M.

Electricity in Horticulture
by A. E. Canham:
Macdonald;
1964; 25*s*.

Mr Canham's book provides a welcome and comprehensive guide to the complex electrical equipment now to be found in use in commercial horticulture. He deals particularly with the principles and practice of the control of plant environment, both aerial and subterranean, with ventilation and shading, refrigeration and irrigation, control of daylength and supplementation of daylight. Other chapters discuss such subjects as electric motors and switchgear, electric wiring and maintenance of electrical equipment. The book is far from being merely a technical guide for electrical contractors as to the special conditions of horticultural applications of electrical equipment. It is written with deep practical appreciation of the practical horticultural aspects of the subject and its advice is supported by frequent reference to relevant research work. It will be of considerable value to growers as well as to all agricultural engineers who are in any way concerned with intensive horticulture. J.A.C.G.

It is regretted that in Vol. 21, No. 1 of the Journal, the title Electricity in Horticulture *erroneously appeared as 'Electricity in Agriculture'.*

Farm Building Design and Construction
by D. Heselton Pasfield:
Temple Press;
1964; 50*s*.

It is only within very recent years that the agricultural public in Britain has awoken to the fact that the importance of farm buildings, in terms of their effect on the productivity of farming and of capital investment, is comparable with that of tractors and machinery. Mr Pasfield's book is intended to provide general information on the design requirements of agricultural buildings, and particularly some of the biological and other factors relevant to successful farm building design. In addition to chapters dealing with foundations, frameworks, roofs, walls and cladding, there are some discussions on the particular requirements of dairy buildings and of buildings for livestock housing and for bulk storage. Building drainage, farm roads and building maintenance are also considered. A great deal of technical and design information is provided, and the book will be of value to anyone concerned with farm structures. It is well-produced and well-illustrated, with an adequate index, and reference is made where appropriate to further sources of information on points of detail. J.A.C.G.

Mechanics of Soil
by Alfreds R. Jumikis:
Van Nostrand;
1964; 85*s*.

Professor Jumikis has gathered into one volume most of the theory of soil mechanics currently available to Civil Engineers. As such, the treatise should be a valuable reference work for those engaged in research including that on the mechanics of granular masses such as bulk cereals or fertilizer. It does not, however, deal with the practical aspects of soil strength measurement nor with the problems of continuously moving loads met in soil/vehicle and implement mechanics that are so particularly important to agricultural engineering. P.C.J.P.

Saga of the Steam Plough
by Harold Bonnett:
George Allen & Unwin;
1965; 42*s*.

Mr Bonnett has written a delightful book which will be read eagerly by all who are interested in agricultural steam engines. He has traced the development of invention and technique, as well as the development of steam engines themselves, from the early seventeenth century onwards. The book is in no sense intended to be an engineering treatise, but deals with the design of steam engines and their mechanisms in fairly general terms. The merits of various systems of rope haulage and of direct traction of ploughs and other implements are discussed, and reference is made to digging machines and other steam-powered implements. Mr Bonnett's book is most readable, and contains a wealth of anecdote and comment. It is illustrated by line drawings and monochrome plates and has a satisfactory index. It is a valuable contribution to the literature of one of the most appealing facets of agricultural engineering. J.A.C.G.

All publications reviewed above have been acquired for the Institution Library

The Annual Dinner of the Institution

London, 22 April 1965

The Right Honourable Earl de la Warr, PC, GBE, proposing the Toast of 'The Institution of Agricultural Engineers', stressed the need for modernization and said that as an industry agriculture could feel proud of its record during the past 10 or 15 years. No country had made greater advances and the contribution to the nation's exports was outstanding. In the matter of education, Earl de la Warr acknowledged that the National Diploma in Agricultural Engineering had played an important part in establishing a status for agricultural engineers based on real qualifications. He wondered, however, whether there was a gap below that standard; a need for more short courses related to the operation and care of the new and highly complex machines being used in agriculture today. In this respect he felt that Britain had little to learn from the U.S.A. but did, on the other hand, have a lot to learn from that country in regard to buildings, livestock problems, methods of making and drying hay and grain drying.

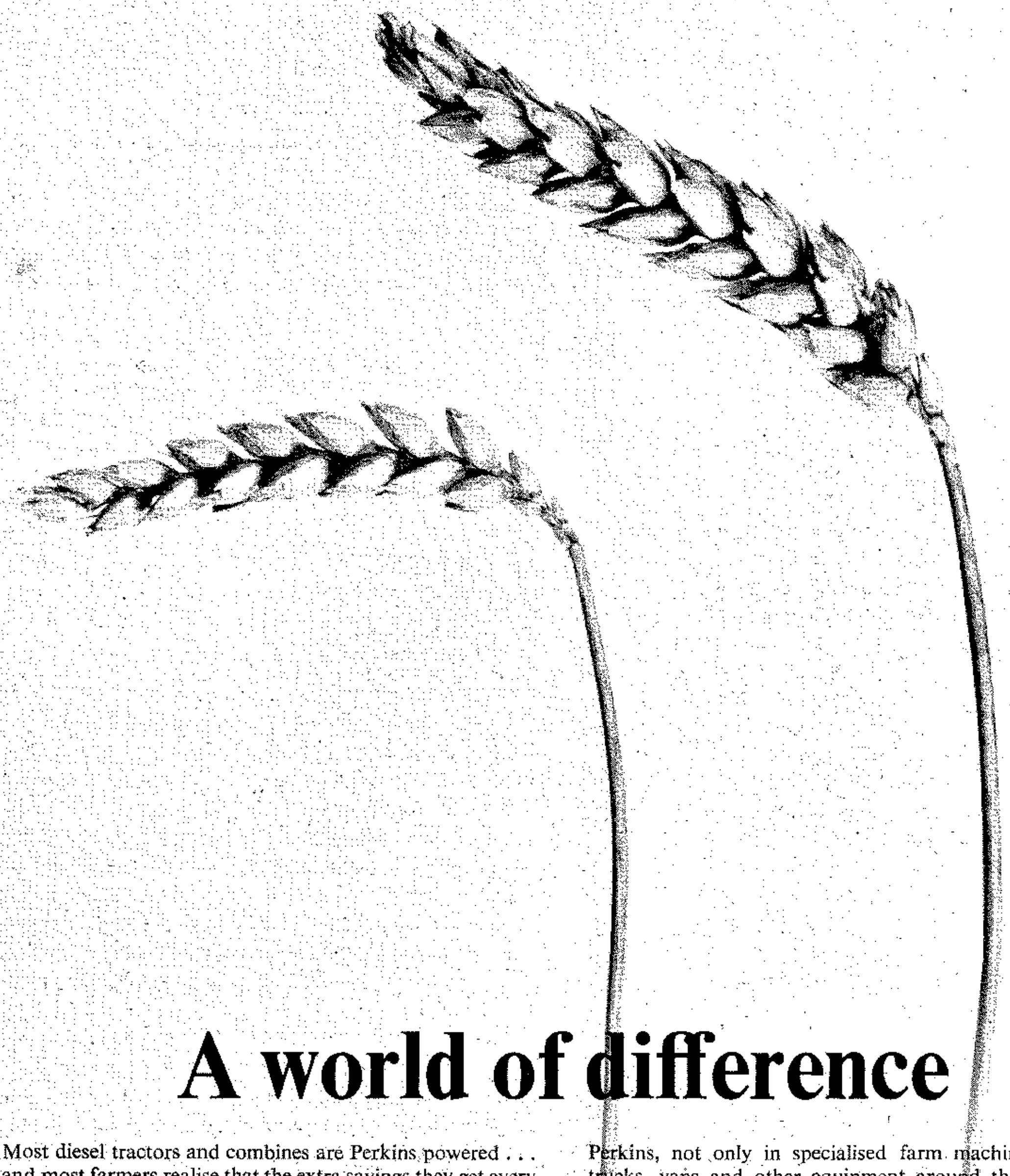
Earl de la Warr went on to recount his recent experiences in the African Continent which he had visited in his capacity as Chairman of the United Kingdom Committee of the Freedom from Hunger Campaign. He had been infuriated to find that although the United Kingdom had given tremendous help in money and resources to establish farm institutes it all too often resulted in American machinery then being employed. He wondered whether a big opportunity had been missed by British machinery manufacturers and believed this might be somewhat typical of this country at the moment. Nevertheless, he paid tribute to the furtherance of agricultural engineering through exports; through the work carried out by the National Institute of Agricultural Engineering; by the Institution, with special reference to the National Diploma in Agricultural Engineering; and in the training given at the National College of Agricultural Engineering.

Responding to the Toast Mr J. H. W. Wilder, BA, MI AGR E, thanked Earl de la Warr for his interesting and informative speech. The President said that the Freedom from Hunger Campaign in which Earl de la Warr figured so notably was an example of an organization concerned only with giving and helping. Agricultural engineers had a great contribution to make towards solving the problem of hunger in the World, as indeed the immediate Past President Mr W. J. Priest had so admirably expressed in the excellent Wakefield Memorial Lecture which he had given at the Chelsea College of Aeronautical and Automobile Engineering almost exactly a year previously. Among the members of the Institution present at this Annual Dinner, there were many whose work was concerned with agricultural engineering research and development. Agricultural engineering, like farming, was a practical down-to-earth business and research and development could only advance with the help of farmers, of whom Earl de la Warr was himself one, who were willing to put new ideas into practice on their farms.

This Dinner was the one occasion each year when the Institution was able to thank all those who had supported it; the affiliated organizations whose contributions both financially and in other ways were so valuable, the firms who gave scholarships and the officers of the Institution's various branches who gave so much of their spare time to organizing the many branch activities. The Institution's primary objective was to promote the general advancement of agricultural engineering and this was achieved by setting educational standards, initiating discussions and conferences and publishing technical articles in the *Journal*. By providing professional status for the agricultural engineer the hope was that some of the ablest talent in the country would be available to the industry. In a highly competitive world the industry had to compete with others for the top stream of school leavers and university graduates.

The magnificent export performance of the tractor industry was setting a challenging example for other British industries to follow. This success of the British tractor overseas gave machinery and implement manufacturers a wonderful export opportunity which should be fully exploited. To succeed in this it was essential that entrants into agricultural engineering should be of the very highest quality. The Institution was playing an important part by raising the status of the qualified agricultural engineer and congratulations were due to the Examination Board in Agricultural Engineering and the Education Committee of the Institution on the work they were doing in this connection. It should also be

(*continued on page* 89)



CURRENT TRENDS IN GRAIN DRYING

by P. H. BAILEY, BSC (ENG), AMI AGR E*

Presented at the Annual Conference of the Institution in London on 22 April 1965

Introduction—drying, or storage without drying

Currently, the practice of drying grain for storage on the farm in the U.K. is going through perhaps the most critical but interesting phase in its history. On the one hand the balance between the popularity of different methods of drying is changing; on the other hand, the desirability of drying at all is in question. Other papers in this issue (Culpin, Hyde, Munday), deal with the principles and practice of storage without drying, but the applicability of the drying process may be briefly examined here in the context of possible alternatives.

Trends in cereal production in the U.K. since the war are illustrated by Fig. 1. The total annual production of

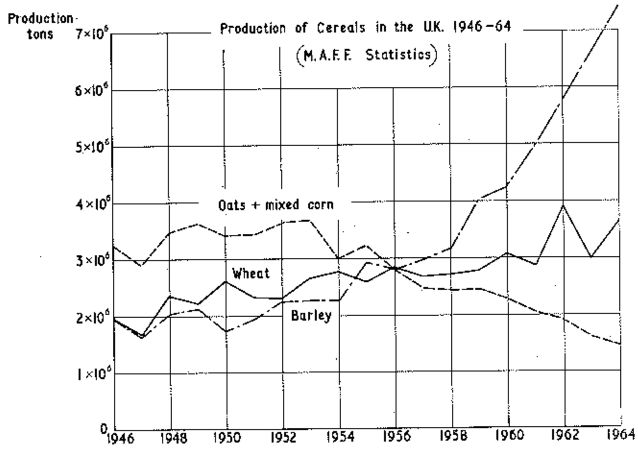


FIG. 1

Production of Cereals in the U.K. 1946-64. (M.A.F.F. statistics)

cereals has risen fairly steadily, mainly through increasing yields; wheat production has followed this trend, but the production of barley has soared to nearly four times the 1946 figure from an increased acreage as well as through increase in yield per acre. The economic and cultural reasons for these trends are outside the scope of the present study: but the quantities and types of material produced have a considerable influence on the system adopted for storage.

The storage system is also influenced by the utilization of the grain. Table I gives a broad outline of the utilization of the total production of wheat, barley, and oats for 1962.

TABLE I

UTILIZATION OF CEREALS IN 1962
(from M.A.F.F.† statistics)

	Weight (thousands of tons)	*Per cent of total*
Seed	570	5
Human consumption and industrial use	3200	28
Stockfeed, sold off farm ..	4380	38
Stockfeed, retained on farm ..	3150	28
Total stockfeed	7530	66
Total seed and sold off farm ..	8150	71

About two-thirds of the cereal production in the U.K. is for stockfeed, but more than half of this is sold off the farm for compounding. Although there is a new trend for compounders to produce some meals designed to balance farm-grown barley rations, which may alter the picture to some extent, it would seem that the present potential for sealed storage is about one-quarter to one-third of the total production: though drying may be continued for much of even this sector of cereal production because of the increased flexibility in disposal of dried grain.

In fact, from 1962 to 1964 there has been an unprecedented increase in the number of grain driers. This is in a period when sealed storage has just started to become a significant factor, and chilled storage has hardly made its presence felt in terms of number of installations. The data plotted in Figs. 2 and 3 from M.A.F.F. statistics for England and Wales bring up to date the information previously presented to the Institution by Williamson (1964). In examining the ratio of combine-harvester population to drier population it should be appreciated that the bare numbers give only an indication of the trend: total combining capacity and total drying capacity have increased at rates greater than the numerical increase, and the ratio of these quantities is probably not exactly the same as the ratio of the numbers. Results of a survey in the East and South Midlands by Jones, to be

* Tractor and Drier Performance Department, N.I.A.E.

† Ministry of Agriculture, Fisheries and Food

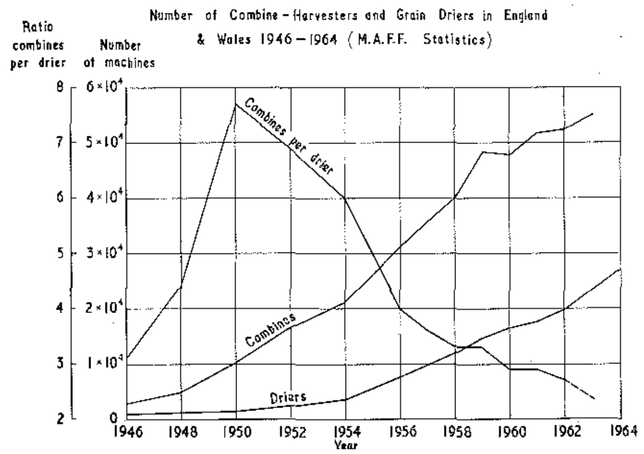


FIG. 2
Numbers of combine-harvesters and grain driers in England and Wales 1946-64 and the ratio between them. (M.A.F.F. statistics)

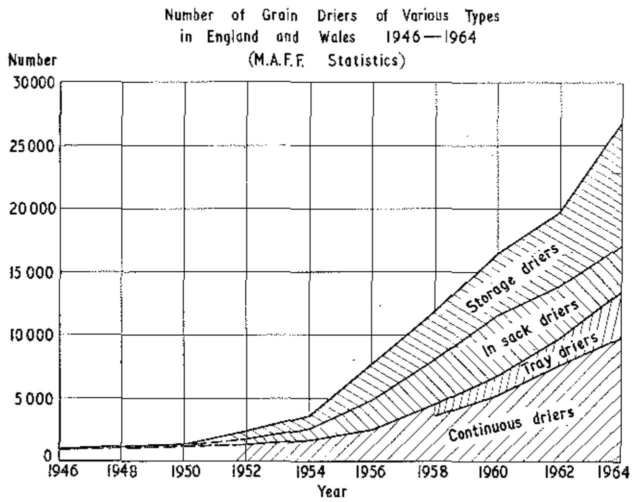


FIG. 3
Types of grain driers in England and Wales 1946-64

published shortly, show in fact that nominal capacity of continuous driers available on farms per foot of combine cutterbar commonly varies between 0.1 and 0.5 tons/hour, with even wider variation reported from a few farms. Bearing in mind that a proportion of the harvest is combined without need for drying, and that there is considerable drying capacity in the hands of the buyers of grain, it is not to be expected that the number of driers will make a very close approach to the number of combines; however, the most recent statistics show a closer approach than could be forecast after the 1962 census. This underlines the dangers of trying to forecast the future mainly on the basis of past statistics, but the past and the present situation can help to bring new ideas into perspective.

Types of drier

Division of the number of driers into the principal types shows that the main increases in numbers have been in continuous driers and—above all—in storage driers. The proportion of storage driers has increased from 29 per cent of the total in 1962 to 36 per cent in 1964. It may be surmised that many of the storage driers have been installed by farmers with smaller cereal acreages who had formerly relied on drying facilities provided by contract or by the purchasers of the grain, or who hoped to harvest without the need for drying. Installation of drying facilities by small cereal growers is perhaps more an insurance against inability to have grain dried when the need arises in a bad harvest than a systematic investment to obtain better prices for grain sold off the farm in an average harvest.

Although an increase of over 2500 in the number of continuous driers has been recorded, the proportion of this type has dropped slightly from 37% to 36%. An increase of 1200 in the number of bulk batch driers represents an increase in the proportion from 13% to 14%. On the other hand, platform in-sack driers have decreased in actual numbers by 510 and in proportion from 21% to 14% of the total. This decrease reflects the change from bagging combines to bulk handling. Even where bagging combines are still in use, the objection to in-sack driers is the amount of handling required, which on the smaller farm is doubly unwelcome as it represents further work for the farmer or his man after a hard day on the combine. It is known that some platform driers have been converted to tray driers.

Batch driers

Although in the period under consideration bulk batch driers have increased in numbers, their future is a matter of speculation as combining rates increase. Seen from the drying shed, grain harvesting is a batch process, as trailers full of grain arrive intermittently from the field. A batch drier capable of dealing with the grain at its mean rate of arrival is in some ways an ideal arrangement; but with modern combining rates of around $\frac{1}{2}$ ton/hour of grain per foot of cutter bar width a small batch drier is likely to be relevant only to the smaller machine. A small batch drier can be incorporated in a bulk handling system including a large holding silo for incoming grain, in which the grain can accumulate until it can be accepted by the drier; in such a system it is of course necessary to ensure that the daily combining capacity does not exceed the daily drying capacity if the drier is not to be the bottleneck. An alternative approach to the use of batch driers is to provide a drier big enough to accept the daily output of the combine as one batch. At least one make of drier with this approach in mind has been marketed recently. A variant of the large batch drier that has been available for some time is the use of a radially ventilated silo as a batch drier with higher airflow and much higher temperature rise than when using storage-drying techniques.

As the author has previously pointed out (Bailey 1964) specific consumption of batch driers is usually reasonably low, as with the favourable ratio of bed depth to air quantity in most designs the exhaust is saturated for a large proportion of the total drying time. However, the good thermal economy is associated with a marked moisture content gradient, both in theory (e.g. M'Ewen and O'Callaghan 1954) and from the evidence of test results (e.g. N.I.A.E. 1957), and it is desirable that grain dried in batch driers should be well mixed before putting into bulk store.

Continuous driers

In the early days of the combine-harvester in the U.K., flour-mill practice was followed in providing vertical continuous driers for grain, although continuous driers of simplified design were fairly soon evolved. By 1945 investigations were being carried out on other methods of drying grain to 'lighten the burden of dealing with combine-harvested grain on small and medium-sized farms' (Cashmore 1947); with the general introduction of in-silo drying and platform sack driers about 1947-9 it could have been supposed that continuous driers had served their purpose in agriculture, but in fact the new systems supplemented rather than supplanted them. It remains to be seen what will be the eventual effect of the new systems attracting attention today.

Continuous driers appear to have remained popular because of the opportunity they offer in a well-planned installation of having grain safe in store within hours of combining. Working with comparatively high drying air temperatures they are nearly independent of ambient conditions, and they are capable of dealing with grain of high initial moisture content without undue difficulty, though drying in two stages is recommended when moisture content is particularly high.

With the competition from storage driers and other comparatively inexpensive systems, there has been a trend apparent for some time for continuous driers for farm use to be constructed at the lowest possible first cost. Technical sophistication to give the highest possible thermal economy cannot be justified in a machine working only a few weeks in the year unless it can be combined with simple construction, as the increase in capital charges on an elaborate drier may more than outweigh a small saving in fuel. A fuel consumption of about 3 gallons per ton when drying from 21% moisture content to 16%—i.e. 2900 Btu per lb of water evaporated—is evidently acceptable. Similarly, the solid construction necessary for 24 hours per day, round the year working in a mill drier would be uneconomic for normal farm use. However, with capital cost ranging from about £800 for a 1 t/h drier through about £450 per ton per hour for a $2\frac{1}{2}$ t/h drier and down to as low as £260 per ton per hour for a 10 t/h machine (all for the bare drier) it seems that the limit of economy in first cost is being approached if it has not already been reached (Fig. 4). With the lower unit cost of the larger sizes, it follows that the larger continuous driers are the most able to compete with alternative systems, and the trend is consequently for

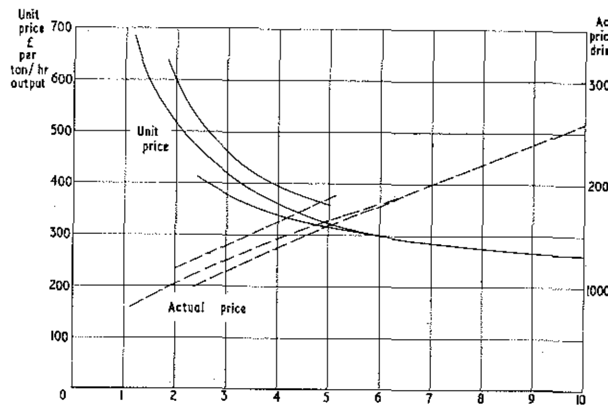


FIG. 4
Prices of continuous driers as affected by size

the smaller sizes of continuous drier to disappear, while sizes are coming into use on farms that were formerly used only in mills or other large grain handling concerns.

An aspect of the trend to larger sizes that may be mentioned in passing is the tendency to greater realism in recommended hot air temperatures. The M.A.F.F. recommendation for the hot air temperature limit for grain for feeding is being raised from 180°F to 220°F, provided adequate cooling is available. Where input moisture content is known, hot air temperature for seed grain and malting barley may be varied in accordance with the scale recommended. However, the maximum hot air temperature recommended for milling wheat remains at 150°F, and there is some evidence that complaints by millers about bad drying can be linked with excessive hot air temperature.

Another trend that has become apparent is for driers to be of unit construction, designed to be placed on a flat floor with little if any special foundation work. Some types can in fact be delivered complete, connected to fuel and electricity supplies, and be ready to operate straight away. This is in contrast to earlier continuous driers which required intricate foundations and a good deal of site work in erection.

An important factor in this trend to easy installation has been the change from the large masonry furnaces that were common with solid fuels and used for early oil burning driers, to the coaxial steel air heaters that are now universal on driers for the home market. British drier manufacturers exporting to certain countries on the continent are finding it necessary to offer a heat exchanger, as in some countries the use of direct-fired driers for grain for human consumption is prohibited, and in West Germany subsidy is available only for indirectly heated driers. Bolling (1964) has shown that there may be a small but significant uptake of 3, 4 benzpyrene by grain dried with direct-fired oil heaters, but experiments in this country suggest that the uptake of products of combustion is only in the outer layers of the grain which are removed in the milling process.

There is a trend for driers to be designed not to create a dusty atmosphere. Mill driers have been enclosed and their exhausts ducted outside the building for many years, but until recently most farm plants have discharged the exhaust inside the building, making working conditions at least unpleasant and leading to corrosion of the building, damp ambient conditions of the grain store, and deposition of dust on everything in the drying plant. Apart from the driers based on mill practice which work under a positive pressure, with fan between air heater and drying chamber, but are totally enclosed, two methods are used to avoid the discharge of dust: (1) the fitting of a hood, with a low pressure extractor fan with a volume capacity somewhat in excess of the main drier fans, and (2) layout of the drier design with the main fan downstream of the grain chambers. The second alternative has the advantage of being intrinsically clean, any leaks being *into* the drier, but it is liable to lead to trouble with stratification of furnace air and diluting air streams from the furnace, which can however be overcome by appropriate design of the air heater (N.I.A.E. 1965).

The full advantage of continuous drying can only be reaped if the process becomes virtually automatic. A simple interlock between fan and air heater has been common practice for many years, but control panels giving interlocks between the hot air system and conveying systems are becoming more common. A form of automatic control based on monitoring of the grain output by a high frequency capacitance bridge has been developed and tried on two makes of drier (Matthews 1964) but is not yet commercially available.

Cooling grain after drying

The safety of grain in store is a joint function of moisture content and temperature. Burges and Burrell (1964) have indicated the relationship between the safe limits as governed by insect heating, fall in germination, and fungal heating, and this is discussed by Hyde (1965) and Munday (1965) in relation to the chilling of grain at high moisture. It may be noted however that even at the moisture content of 14% normally regarded as safe for bulk storage trouble is liable to occur if temperature is higher than about 60°-65°F. The daytime ambient temperature at harvest time is not likely to be lower than this, and grain discharged from continuous or bulk batch driers may commonly be 10°-20°F higher. Records of the temperature of grain in store in the 1960 and 1961 harvests (Williamson 1964) show that the grain went into store at temperatures between 70°F and 90°F and that the cooling curves lagged 2-3 months behind the mean ambient temperature, the safe temperature of 60°F not being reached until October-December depending on the initial temperature. Out of a sample of twelve stores in which temperature readings were made, serious heating occurred in one and slight heating in another, though the instances of heating affected only a very small proportion of the grain harvested on the farms concerned.

Satisfactory cooling can be obtained by the use of a small fan connected to simple ducts in silos, or to lateral ducts at wide spacing in floor stores, and used to ventilate the grain with cool night air. An airflow of the order of 20 ft³/min per ton of grain stored appears to be adequate for cooling to a safe level within a few days of drying; depending on ambient temperature and the grain temperature before cooling, this amounts to a total air supply of 2000-4000 lb of air per ton of grain stored.

Storage driers

The quantities of air involved in storage driers are of course far greater than those in the simple cooling systems discussed above, amounting to 100-200 ft³/min per ton of grain, or a total supply of the order of 100,000-200,000 lb of air per ton of grain stored. It is a well-known characteristic of storage driers that they operate with large quantities of air and small temperature rise, though the total quantity of energy supplied may be of the same order as the total quantity in driers with a larger rise. It is not always realized that nearly all the energy expended in driving the fan becomes available as heat; the fan losses raise the temperature of the air a degree or two, and the kinetic energy of the air leaving the fan is nearly all converted into heat through friction with the grain mass, the kinetic energy at exit being very low. Consequently the major part, if not all, of the energy required may be supplied at the fan shaft.

This is illustrated in Table II, which is extracted from a test report on an in-silo drier (N.I.A.E. 1964).

TABLE II

Moisture content of grain before drying 21%
Ambient temperature 55°-59°F
Barometric pressure 1013-1021 mb

Ambient r.h. %	*Mean final m.c. %*	*Energy required per ton of dried grain*		
		for heaters kWh	*for fan kWh*	*heat equivalent of total, therms*
75*	16	0	49	1.7
	15	0	59	2.0
	14	5	67	2.4
80*	16	0	59	2.0
	15	0	72	2.4
	14	26	65	3.1
85†	14.8	56	47	3.5

* Results calculated
† Actual test conditions

Table II throws light on two current trends: the use of fans without fixed heating arrangements, and its concomitant—provision of supplementary heat by portable heaters. It can be deduced from the diagram of safe storage temperatures and moisture content (Burges and Burrell 1964, and Hyde 1965) that the moisture content of 14% formerly regarded as the maximum for safe storage in bulk can be exceeded if equipment is available to reduce the temperature to a suitable level by periodic ventilation as the season progresses. This has the advantage that the weight of grain for sale is not reduced unnecessarily by excessive drying, and the energy consumption is reduced. Provided ambient humidity is not too high, adequate drying can be obtained with the natural drying potential of the air together with the energy imported from the fan shaft: but as indicated by the last line of the table, in a year in which the humidity is high supplementary heat may be required. 'Waste-heat' units provide direct heat from the engine losses, and their use is distinct from that of fans without heaters.

Cover (1964) has recently described to the Institution the general advantages of in-silo drying. There is a trend for in-silo driers to use higher rates of airflow than formerly, so that drying can be completed in a shorter time and grain at higher initial moisture contents may be dealt with safely. In-silo driers have become available as 'package deal plants' in which the manufacturers supply all necessary equipment apart from the foundations, in contrast with the earlier individually designed plants for which the farmer or specialist firms had to act as contractor.

In-silo drying plants are particularly adapted to completely mechanized handling with low labour requirement, but until recently the emptying of the last few tons from each bin was inevitably carried out by manual labour. The introduction of proprietary self-emptying flat floors promises the ultimate reduction in labour requirement with this type of drier.

No trend in grain drying has caused greater interest than the widespread adoption of 'on-floor' drying. Technically the method is basically the same as in-silo drying except for the use of a floor duct system instead of perforated floors. Practically the system has the advantages of low capital cost per ton of grain dried, and the use of a building which is adaptable for purposes other than grain storage should the pattern of cropping change —or even after the grain has been sold. On the other hand, loading and unloading of grain require more labour than in a well-planned in-silo plant (though grain throwers and loaders are improving the labour requirement of these processes), and grain cannot be so conveniently separated into different parcels. On-floor systems are usually designed for a shallower depth of grain than silos, and so require a building of greater floor area.

M.A.F.F. statistics have not so far made a division between in-silo driers and on-floor driers. It is however certain that practical application of the on-floor method has outstripped the availability of technical data. The pressure drop through grain ventilated from ducts was at first assumed to be much the same as that from perforated floors, but recent work by Williamson (to be published shortly) has demonstrated that pressure drops are greatly affected by the outlet area from the lateral ducts. A drying experiment (see Fig. 5) has confirmed the deduction by Brooker (1958), which can also be made from Williamson's work, that the last place to dry in a mass of duct-ventilated grain is—or should be—near the *surface* of the grain midway between ducts. Many reports have been received however of trouble with grain *on the floor* midway between ducts, and it is surmised that this may occur when the floor is not completely damp proof or the water table is high with consequent cooling of the floor.

Practical points sometimes overlooked in the design of lateral ducts include keeping maximum air velocity along the ducts well below 2000 ft/min, not only to reduce pressure losses but to avoid trouble with pneumatic

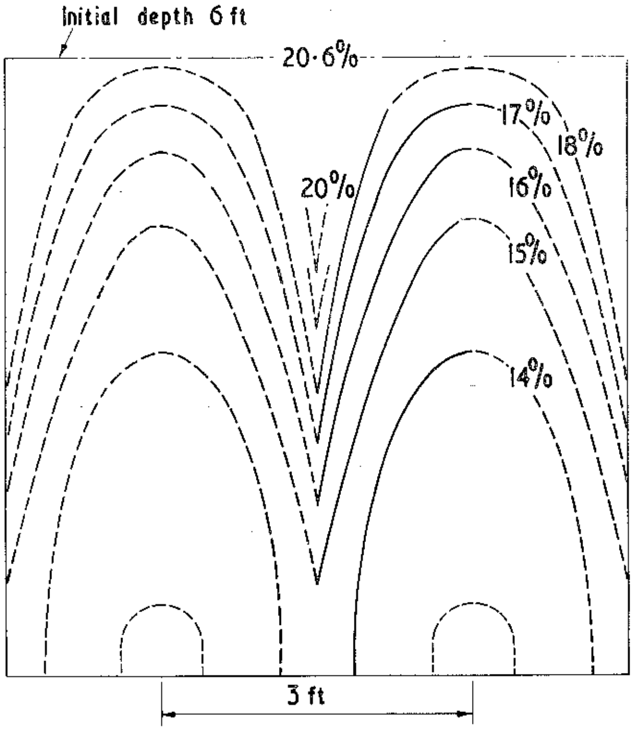


FIG. 5

Zones of equal moisture content in grain dried by ventilation from floor ducts

conveying of grain along the ducts creating a blockage. Turbulence may occur where the laterals join the main ducts, and grain may consequently leak into the ducts at local low pressure areas, be conveyed along the duct by the local high velocities and cause the ducts to block; care should be taken in the design of the junction of the main ducts and laterals to ensure that there is no place where grain can enter. In comparison with these practical points, design for optimum air distribution along the ducts is a refinement, but a method for prediction of pressure gradients in perforated grain ducts has been published by Shove and Hukill (1963).

Testing of grain driers

Problems in the testing of grain driers, and the basic methods used in the U.K. for official tests have already been described to the Institution by the author (Bailey 1959). The principal development which has taken place since then has been the formation of a Technical Committee of the B.S.I. concerned with tests of post harvest equipment. A draft standard on tests of agricultural grain driers has been circulated to the industry and the issue of a standard on the subject may be expected in the near future. The draft includes a section on tests of in-silo driers as well as specifying tests for continuous and batch driers; the in-silo drier test method is comparatively new, and involves the drying of a typical silo filled with freshly harvested wheat at an initial moisture content as close as possible to 21%, concurrently with a number of other silos. The summarized performance is calculated on the basis of the test results, the assumptions required being too great for the final results to be capable of description as 'corrected' or 'adjusted' (See Table II). Difficulties arise in testing on-floor driers, in measuring the weight of material dried in a typical part of the floor, and in controlling the moisture content of the grain arriving at the chosen part, and a specification for such tests is not included in the present draft.

Methods of correction to specified ambient conditions have been briefly described to the Institute of Fuel (Bailey 1964); present methods are based on the assumption for a drier with near-saturated exhaust conditions that exhaust relative humidity remains unchanged for a small change in ambient conditions, and for a drier where the exhaust condition departs substantially from saturation on the assumption that the drying rate of the grain mass can be predicted by the equation proposed by Morris Thomas (1962). Both these methods are open to objection, and work is now in progress at N.I.A.E. on prediction of thick bed performance by an iterative method, in which the drying of small layers of the grain bed is analysed and the condition of the exhaust air and of the grain at the conclusion of a small element of time in each element of the bed is taken into account in drying in adjacent elements. The method is extremely slow by hand calculation; the graphical method proposed by M'Ewen and O'Callaghan (1954) is workable, but is also rather cumbersome for repeated routine calculation. Berry has evolved a digital computer programme which makes possible the rapid calculation of the successive steps, using far smaller elements of bed thickness and time than were practical with the graphical method. Application of the programme to results obtained on thin and thick layers of the same grain by Woodforde has permitted the checking of predictions, so that approximations can be refined and incorrect assumptions eliminated.

It is envisaged that correction to standard conditions will eventually involve correction to standard parameters of grain condition—bulk density, resistance to airflow, and thin layer drying rate—and these will involve measurements being taken on a sample of the grain on a Test Control Drier. This drier will also be available for estimation of performance under standard conditions by drying a batch of the grain used on test, under test ambient conditions, as an analogue of the process in the drier under test.

Conclusion

Reasonable precision in statement of the technical performance of driers is one essential to making an informed choice of drier, drying system, or system of storage without drying. However, with the many divergent avenues of choice laid open to the farmer by the trends discussed, there is an urgent need for a thorough economic appraisal. Nix (1956) and Theophilus (1955) carried out economic surveys of drying practice in their areas about ten years ago. Since publication of their results the number of drying installations has almost quadrupled—and since the surveys were made, more than quadrupled—and drying practices have changed. It is important that any survey should take full account of the economic cost of the labour and management requirements for proper operation of the various systems, so that their relative value can be put into proper perspective and farmers and manufacturers alike can make a reasoned decision on which of the many current trends are likely to prove most advantageous.

Acknowledgements

The author acknowledges the co-operation of his colleagues P. E. Berry, M. P. Jones, W. F. Williamson and J. Woodforde who have allowed him to refer to aspects of their work which have not yet received formal publication.

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DISCUSSION

MR P. G. FINN-KELCEY (Consultant) asked Mr Bailey to give his views on the advisability of drying grain in greater depths than the 10 ft which was the normal maximum recommendation. Prefabricated structures could be obtained today which were twice or three times that height. Mr Finn-Kelcey wondered what technical difficulties might be encountered, particularly with regard to ventilation. Mr Bailey replied that in his view the difficulty of ventilating to greater heights would appear to be simply one of air resistance. If the height were twice as great the resistance would be likewise twice as much for an existing air flow, but this would imply that the grain at the top of the silo would take twice as long to dry and there was the risk of its going bad at the top. If drying rates were to be maintained, air flow would have to be doubled; resistance would therefore increase fourfold and the power requirement would increase by up to eight times in a 20 ft silo compared with a 10 ft one. Mr Bailey believed it was necessary to make a compromise between the drying rate and the floor space that would govern the height of the silo, though there was possibly a trend towards taller silos. The electricity authorities in some areas were not anxious to limit the size of installations, but the basic considerations which determined the height of floor ventilated silos for drying were cube law applicable to fan power together with the limited availability of drying time.

MR W. G. COVER (Simplex Dairy Equipment Co.) suggested that the answer to Mr Finn-Kelcey's question should take account of radial ventilation as well as floor ventilation. With radial storage bin drying any height could be contemplated and 20 - 24 ft vents were quite common. Mr Bailey said that he had understood Mr Finn-Kelcey's question to be concerned with floor ventilation. However, the right answer to ventilating a very high bin was doubtless radial ventilation as proposed by Mr Cover.

MR G. L. R. REYNOLDS (W. Reynolds & Sons (Bedford) Ltd) commented that many farmers were installing on-floor drying arrangements without having special buildings for the purpose. Even though specially reinforced walls might be necessary they tended to use existing buildings which had not got such walls. He asked if any research on putting grain on the floor to a height of say 3 or 4 ft had been done so that those buildings without reinforced walls could be used for on-floor drying. Mr Reynolds also asked what the effect would be on the width between the ducts if one had a lesser height than say 6 ft., which was usual for on-floor drying. On side pressure in silos, Mr Bailey said he did not know of any recent research that had been done; he believed there was undoubtedly a need for research on angles of repose of grain.* It was still necessary to refer to handbooks and textbooks written in the late nineteenth century on grain storage problems and very little of a factual nature was known on the variation on the angle of repose with different varieties and moisture contents. There was no information about side thrust on low silos or on the effect of the width between ducts, and the work which had been done so far on varying grain depths was limited. Unfortunately, work at Silsoe on this subject had been concluded, but some work was being done at the University of Newcastle-upon-Tyne and also, he believed, at the N.I.A.E. Scottish Station and he looked forward to definite information becoming available. In general, Mr Bailey continued, the lower the grain depth the closer together the ducts would have to be. Work at N.I.A.E. had been done with a 6 ft depth of grain, which was about the lowest normally considered for floor storage, and nominal duct spacings had been 3 ft and 6 ft. With a grain depth of 3 ft then a width of 3 ft between ducts would be the very maximum. With thin layers of grain the shape of the duct was important and solid ducts might be desirable because they allowed the air to be introduced to the grain near the floor, a consideration which might be more important than the fact that these ducts offered a higher resistance to airflow than some alternative types. Mr Bailey suggested as a rule of thumb, that he would never want to put the ducts further apart than the minimum grain depth, but added that he had no scientific basis for saying this.

MR D. R. BOMFORD (Bomford Bros) asked whether in the interests of economy in the use of heat it was desirable to measure the relative humidity of exhaust air and if so what was the practical expectation that it might reach 100%. Mr Bailey replied that generally speaking he believed the farmer was not going to be in a position to improve his thermal economy by measuring the relative humidity of exhaust air. This was more necessary in the British Standard drier test to correct results. With the proposed computer technique of performance correction, measurements of exhaust humidity would be used to check that the performance predicted by the computer for the test conditions corresponded with what actually happened on test. The basis of the correction method envisaged was that the computer would be fed parameters of the grain and air and would calculate what the drier ought to have done. This calculation would be compared with the test results including humidity and the parameters would then be corrected until the computer was able to predict the drier performance with some accuracy. The parameters for the standard grain and standard air would then be changed in order to find out what the drier would have done under standard conditions.

In practice, the farmer set his continuous drier to give the output he required and he would not bother to adjust thicknesses and so on to get the maximum efficiency. All the economic data suggested that farmers chose the cheapest drier that worked well, rather than the one that was the most thermally efficient. Depending on design, with a continuous drier one might need anything from 1800 Btu to 3000 or even 4000 Btu to evaporate 1 lb of water in normal drying conditions, compared, of course, with 1100 Btu as quoted in the steam tables for boiling

* Since the date of the meeting, Mr Bailey's attention has been drawn to the following reference:
FOWLER R. T. & WYATT F. A. (1960); 'The effect of moisture content on angle of repose of granular solids.' *Aust. J. for Chem. Engnrs.* **1**, 5.

water not in the presence of air. It was the presence of air, of course, which limited the maximum possible thermal economy. One came nearest to attaining this with a very thick grain bed and under these conditions the relative humidity was controlled more or less by the equilibrium with the grain on top. For instance, with a ventilated bin or floor store with 21% grain on top a relative humidity at exhaust of 90% could be expected. This, of course, would drop if drying was carried out right up to the surface as should be done towards the end of drying. Mr Bailey thought it was reasonable that the thermal economy should be such that in normal practice somewhere between 2000 and 3000 Btu was needed to evaporate 1 lb of water.

MR W. T. W. CORY (Carter Thermal Engineering Ltd) drew attention to Mr Bailey's references in his paper to the requirement in some continental countries that the products of combustion should not pass through the grain. This, as stated, must refer to indirect air heaters where oil or similar fuels were employed. Mr Cory said he understood that in Switzerland the cereal administration would not handle any grain that had been dried by direct-fired methods and in Germany there was now no subsidy on direct-fired plant. He wondered whether Britain was lagging behind in this respect, although he believed the usual answer from those who advocated direct oil-fired heating was that if the air were kept smoke-free, then everything would be in order. However, sulphurous compounds were formed and he believed these were readily absorbed by moist grain; carcinogenic hydrocarbons were also formed and somebody had said that these were enough to make the conscientious grain drying engineer turn to smoking again. Did Mr Bailey feel that research into these factors was needed and would he recommend that manufacturers standardize on indirect heaters, both for this country and for export and should the Government take appropriate steps to encourage this? Mr Bailey said he appreciated this was a question to which, naturally, everybody was anxious to find the right answer. Certain unpublished work in Britain tended to suggest that such materials absorbed by grain were mainly absorbed into outer layers. They were lost in the milling process and did not go on for human consumption. One had also to bear in mind that a good deal of grain went for stockfeed. The content of 3, 4 benzpyrene which had been reported by Bolling in his article in Die Mühle in October 1964 was small but significant. There was no more in some grain that had been dried in modern driers than there was, for instance, in grain harvested from fields alongside a main road where it had picked up from vehicle exhausts. Nevertheless, it existed and Mr Bailey believed that it would be desirable to find out how important this quantity was. The quantity involved in eating a few loaves of bread was not really comparable with what one absorbed in smoking. While he agreed that there was a need for further research, he did not believe there was any reason for alarm at the moment.

With reference to the storage of grain on the floors of general purpose buildings, MR E. C. CLAYDON (E. Electricity Board) said he thought it was obvious that grains stored in this way needed very large buildings unless retaining walls were built. Was there any evidence to show that the provision of buildings with extensive retaining walls and divisions was any more economic than the storage of grain in tall bins with very limited roof space? In reply Mr Bailey said he frankly did not know that there was any evidence and this was why in the conclusions to his paper he had appealed to the economists to provide some information on this subject. He thought that a general purpose building might be a good idea inasmuch as if did not tie one down to grain, so that if the farmer was faced with changed conditions he was not saddled with a heavy investment in a building that was suitable only for grain. The retaining walls would, of course, have been put in for grain, but they would not make the building unsuitable for other purposes. Some farmers used their flat grain floors for other purposes after the grain storage season, but naturally if one was going to make the best of the market one could not rely on having the floor space available at a given time. Mr Bailey said he hoped regional agricultural economists would produce evidence on these points.

Good walls & bad walls!

MR T. P. GREGORY (Rex Paterson Farms Ltd) said that he had stored grain during the last 12 years in substantial quantities on the floors of buildings which could not really be described as general purpose because one of the more successful stores was an old cowshed. It had chalk walls of about 2 ft in thickness which he would not describe as very strong but he had always stored grain in them to a depth of about 8 ft deep, right across from one side to the other and nearly to the top of the wall. He had been assured that the walls would collapse but this had not happened. Since his experience had been that he could store a great quantity of grain in an area measuring 200 ft × 45 ft to a depth of 8 ft with absolutely no trouble at all, he would like to know exactly what the danger heights were for ordinary walls with no particular reinforcement. Mr Reynolds said he had seen grain stored to a height of 3 ft against an ordinary asbestos-sided building—it had caused the asbestos sheeting to bow somewhat, but had not pushed the side of the building out at all. Mr Bailey said that he did not know the answer to Mr Gregory's question, but what Mr Reynolds had said gave point to his own earlier remarks to the effect that there was a need for research at angles of repose and on lateral pressures for low walls, with modern types of grain. The very important point that Mr Reynolds had raised was the difference between what one could get away with and what any expert would dare to recommend though 'experts' on grain drying and grain storage relied to a certain extent on guesswork ? unless they were putting up a very tall silo by the old formulae. In grain drying one could often get away with leaving grain in store at perhaps 16% or 17% moisture content, when it ought to be 14%, with no ill effects. Perhaps the particular decay organisms were not there or it happened to be cold in the places where they were, but sooner or later trouble would arise. The same principle applied to storing grain against asbestos cement walls; if the moisture content was high enough one would get away with it until, perhaps, a drier batch of grain might be stored there and somebody would walk over the top and the walls would burst. There was no safety factor in such cases and Mr Bailey believed that nobody would recommend using asbestos walls under those conditions if there was a possibility of somebody walking by on the other side.

In answer to a question as to whether there was any practical limit to the length of the lateral duct in a floor drying installation, having a centre air duct and lateral ducts at 3 ft centres, Mr Bailey replied that he had referred in the paper (Shove & Hukill 1963) to the optimum proportions of the lateral duct—length to cross-sectional area—but for any given cross-sectional area of lateral duct the length was limited. The length was limited in the first place by the static pressure drop along the duct. The computation of the static pressure along the duct was rather complicated, but a method of doing it had been given by Shove & Hukill. Air velocity along the lateral ducts should be limited to 2000 ft per minute partly because this was good practice for avoiding excessive pressure drops and partly becasue the risk should be avoided of conveying any grains that had worked inside to the far end of the duct, eventually causing a blockage. Another point was that if the duct was very long, providing air for a large area with a consequent high velocity, the losses at the change of section from the main duct to the lateral ducts would be high and there would be high turbulence in the junctions. These would be further points at which grain might be sucked in through cracks and cause blockages.

In reply to a question from MR H. G. PRYOR (Farmer) about reapplication of moisture to grain before selling it, Mr Bailey replied that he always felt it was a peculiar state of affairs that grain should first be dried in order to keep it safe for storing and then had water reapplied to it before selling it. There were several ways of doing this; it could be damped by using, for instance, one of the water wheel metering devices that were on the market. It was the practice at the N.I.A.E. to dampen grain prior to drier tests. It used to be done by means of a hose filling a watering can fitted with a rose and by shovelling the grain in order to turn it, but at Silsoe for the past 4 or 5 years they had been using an auger with a hosepipe connection just above the intake end. A semi-positive water meter was used for metering the water through; the grain rate through the auger was known and therefore the moisture content could be adjusted, normally rising from 15% to about 21% in one operation. The water, of course, took some time to soak in and in order to obtain even damping it was necessary to turn the grain several times in preparation for a drier test. The N.I.A.E. practice was to turn it six times in the course of about 2 or 3 days. It was possible to put in about 2% and this would soak in immediately, but if one applied as much as 6% and put the grain into a bin, there was a risk that it would swell and burst the bin walls and furthermore a lot of water would run down to the bottom. A cheap and simple way of putting water into grain was to use the auger but one must keep turning it for 2 or 3 days afterwards. The rate at which water would go into grain had been indicated by the Cereals Research Station (Campbell & Jones 1955) to be a function of temperature, i.e. the higher the temperature the more quickly would the water go into the grain. Mr Pryor asked whether any research had been conducted into the behaviour of grain as it became wet and whether any technical information was available. Was there serious danger of bursting bins? Mr Bailey said a paper was available which described work done in Mr Woodford's Department at the N.I.A.E. (Browne 1962) on the variation of bushel weight with moisture content. This did not specifically refer to re-wetting but the effects on re-wetting could be inferred from these results.

In answer to a question as to what new trends were discernible in heating, such as micro-wave or infra-red processes, Mr Bailey said he must confess to being rather cautious in his approach to new trends in heating. Although much interest was always shown in new heating methods, he believed it was desirable to use these rather elaborate and sophisticated methods of heating only when warming up air with a furnace, and blowing it with a fan through the material to be dried would not work for some technical reason. Mr Bailey believed that most attempts in the past to use unusual methods of heating for grain drying had failed through technical complexity and too high a cost in relation to processes where special treatment was not really needed, for which hot air drying was good enough and had been quite satisfactory for farm use.

MR E. ATKINSON (Shell Mex & BP Limited) commented partly in connection with the paper by Mr P. H. Bailey and partly also in relation to the fatalities mentioned, on the existence of 3, 4 benzpyrene as a product of partial combustion. An earlier questioner had asked about the effect of this upon grain dried in a continuous drier. Mr Atkinson said that in circumstances of continuous combustion such as one had with a grain drier, products of partial combustion such as 3, 4 benzpyrene were not produced in measurable quantities. It had been alleged that this product caused cancer, although to see this in its correct perspective it should be said that the present experiments had shown only that 3, 4 benzpyrene in a tar acid had caused cancer of the skin of a mouse. Intermittent combustion as in a diesel engine could result in the production of 3, 4 benzpyrene only when combustion was particularly bad due to very poor mechanical condition of the injection equipment. However, said Mr Atkinson, as this was not produced in continuous combustion such as one had with a grain drier the question of possible ill effects did not arise in the kind of situation being considered.

REFRIGERATED GRAIN STORAGE

by G. D. MUNDAY, A INST R*

Presented at the Annual Conference of the Institution in London on 22 *April* 1965

SUMMARY

This paper deals with the practical aspect of refrigerated grain storage, examining the various ways in which the system can be incorporated into conventional storage installations. The design and construction of the refrigeration plant is discussed, the method of operation is explained and the size and operating costs of a range of chilling units are given. The results of a series of tests with an 'on floor' system are shown and commented upon.

INTRODUCTION

It is clear from what can be learnt of present day trends that the feeding of beef cattle and to a lesser extent pigs and chickens, with moist barley is both popular and profitable. Today a large quantity of barley is dried and stored only to be wetted at a later date prior to rolling for feeding purposes. With the introduction of refrigerated storage the need to dry is eliminated and grain at 20% moisture and above can be stored in perfect safety to be rolled in that condition when it is required. It also appears that the product so treated is of better quality and the risk of virus pneumonia due to dust is almost entirely eliminated. Current experience on barley beef feeding would indicate that barley at over 22% average moisture is not necessarily desirable and there may be a case for drying barley down to this figure and then chilling, if it is harvested at a higher moisture content. Another fact which must be noted is that the higher the moisture content the lower must be the holding temperature in order to (a) maintain germination and (b) prevent mould growth.

At harvest time on many farms existing drying capacities are unable to deal with the flow of grain and harvesting may be retarded. This need not necessarily be so with refrigerated storage. High moisture grain may be held until the harvest rush is over, when it can be dried at leisure to the required moisture by the existing dryer at the rate at which it is designed to operate.

There is also the case for refrigerated storage where a farmer intends to increase his acreage of cereals and is, more often than not, faced with the problem of buying a larger drier. In most cases, by the use of refrigeration the existing drier can handle the extra grain, as once the grain is chilled there is time to dry at the existing drier's capacity.

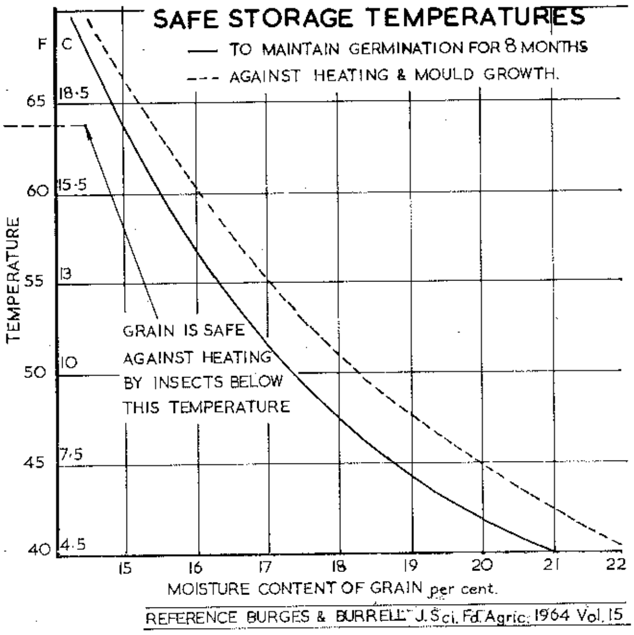


FIG 1

With chilled storage the risk of over-heating by an over-taxed drier is entirely removed. The problems of over-heating are well known and it is not intended to make further mention of the fact in this paper.

One further case for a chilled storage system is on the smaller farm in remote areas where for the moment only a single-phase electricity supply is available. The comparatively small hp of the refrigeration unit enables the plant to be operated on single phase without difficulty. It can be argued here that in these remote areas a drier would not require electrical power and would be driven through a diesel engine or similar arrangement but the cost of such a drier may be greater than the cost of a refrigeration plant to handle the same quantity and the running costs would certainly be higher.

* J. & E. Hall Limited.

METHODS OF STORAGE

On the floor

Grain stored by the 'on floor' method is particularly suitable for chilling providing that the building in which the grain is contained is structurally sound.

Walls must be strong enough to withstand the pressure of the grain and the floor must be of concrete with a waterproof membrane laid in it. Wall constructions can be of brick or alternatively of metal panels which can be obtained specifically for this purpose.

The height at which the grain should be stored depends upon the construction of the building and the strength of the walls. The higher the grain the greater strength must be built into the walls, therefore the higher the grain depth the more costly becomes the building structure. Generally speaking a maximum depth of 10 ft when the grain is level is considered to be satisfactory.

The chilled air is introduced into the grain at low level by means of ducts built into the floor or mounted on the floor.

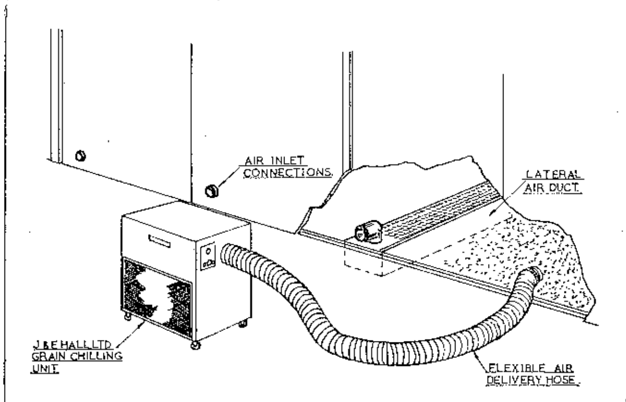


FIG. 2

Underfloor System (J. & E. Hall Ltd. 1964)

The ducts are built into the concrete of the floor and the top of the ducts are flush with the floor level. The ducts are spaced at a distance approximately equal to the depth of the grain at the eaves, thus for a depth of 10 ft the ducts will be 10 ft apart. The duct is built with a recess into which is laid a grid of sufficient strength to withstand the weight of a tractor or loaded trailer wheel. The whole length of each duct is covered by a number of these grids to form one complete gridded opening. On top of the grids is laid an expanded metal sheet made of galvanised steel or aluminium and designed with an approximate strand dimension width of .060 in. and a mesh size of $\frac{1}{8}$ in. This size of mesh prevents the grain from falling through into the duct.

The ducts must run the whole width of the building and each is connected to an external supply point by means of a metal or spun concrete pipe of suitable diameter. The size of the duct should be designed to carry the amount of air which is being provided by the refrigeration plant at a velocity of approximately 1,500 ft/min.

An alternative to the duct system built into the floor is a duct system laid on top of the floor and constructed of wire mesh covered with hessian or expanded metal as before.

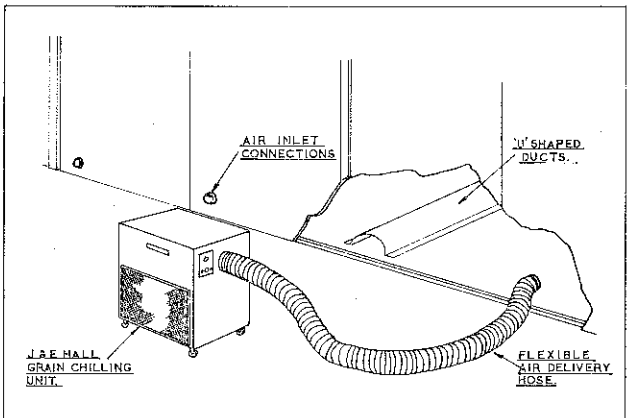


FIG. 3. J & E HALL LTD

On-floor Ducting (J. & E. Hall Ltd. 1964)

The design of this ducting is similar to the under floor ducting in that it should carry the chilled air at a velocity of 1,500 ft/min. With this duct arrangement it is preferable to blank off the top of each duct and allow the air to leave the duct at the lowest level possible in order that the grain actually touching the floor receives the benefit of the cold air.

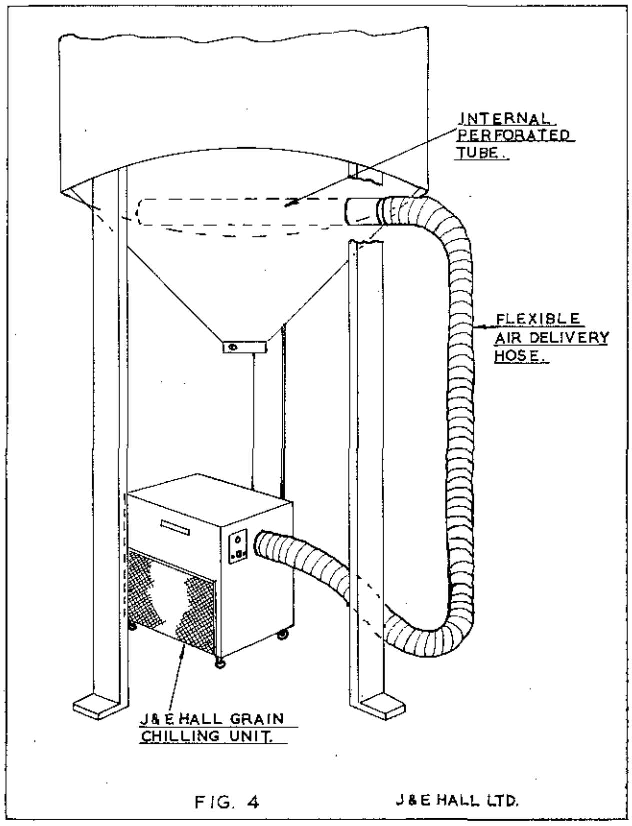
The slight disadvantage of this type of duct system is that it has to be removed as the store is emptied and conversely, each row of ducting must be placed in position as the loading of the grain continues. The advantage of this system however, is that the building is not provided with a permanent duct system and therefore it can be used for other purposes when not used for storing grain. On-floor ducting is also cheaper.

Bins

Grain stored in metal bins or silos, whether they be round or square, presents a different problem as generally speaking the grain is at a much greater depth but does not occupy such a large floor area. Because of the greater depth of grain, greater air pressure is required to push the chilled air through and this reflects upon the hp of the air circulating fan. A bin system can however be adapted to this type of storage quite simply by the use of ducting inserted into the bin.

The duct is inserted into the bin and it is normally only necessary to provide one duct for each bin, of a size to carry the required amount of air through it with a reasonable velocity. The top of the duct, or three or four sides of the duct can be provided with a series of perforations through which the air is allowed to pass.

A bin installation is almost invariably a permanent fixture and it is therefore desirable to have a permanent ducting system arranged at low level to supply air to all the bins. The air supply to each bin is controlled by means of some simple form of flap valve which can be opened and closed as desired.



Bin Storage (J. & E. Hall Ltd. 1964)

With a large bin installation the refrigeration plant can be of sufficient size to handle more than one bin at a time if this is found to be more economical.

With chilled grain in metal bins care must be taken that the surface of the bins on the outside are protected against direct sun heat, as otherwise there is a danger of the outer layer of grain, where it touches the inside of the metal bin, heating up and becoming mouldy and possibly subject to mite infestation.

The protection on the outer surfaces of the bin should consist of a thin skin of insulating material such as fibre-glass, polystyrene or even asbestos sheet, in fact any form of recognised insulating material used for buildings would be suitable for this purpose.

Although there is not a great deal of experience of chilled grain storage in metal bins it must be obvious that whenever possible the surfaces of the bins should be protected from excessive heat.

Where concrete bins are used the problem is not so acute as the walls of these bins are thicker and the conductivity of concrete is much less than that of a thin sheet of steel.

In certain types of grain bin or silo a perforated floor is provided and there is no objection to blowing air through this perforated floor and making use of it to distribute the air through the whole bulk of grain. In this case a simple duct penetrating the side or bottom of the bin would be sufficient.

One interesting fact which might be borne in mind is that in all current grain chilling installations the air is blown through the grain and is then dissipated at the top. In bin installations it would be possible to draw the air collected at the top of the bin back into the air cooling system and this would make a considerable saving on the hp of the refrigeration plant, because the air leaving the top of a heap of grain is usually cooler than the air drawn in from outside. The cooling load of a given quantity of air is directly proportional to the temperature difference between air entering and air leaving the cooling coil.

The ducting system however to provide this arrangement might be rather expensive and difficult to manage.

THE REFRIGERATION UNIT

Basic Principles

Refrigeration deals with the transfer of heat from a low temperature level 'the heat source' to a high temperature level 'the heat sink'. The basic laws of thermodynamics show that power must be expended in any continuous refrigeration cycle since heat of itself cannot flow against a temperature gradient. In the case of a compression cycle, power is introduced into the system by compressing a gas or vapour from a low suction pressure to a high discharge pressure, thus creating the necessary temperature lift.

In a vapour compression cycle a refrigerant is employed which changes phase from liquid to vapour as it absorbs heat in the evaporator. A compressor withdraws the vapour generated in the evaporator at a low pressure, raises its pressure and discharges the vapour to the condenser. The refrigerant changes phase from vapour to liquid in the condenser as heat is discarded to the 'sink'. High pressure liquid refrigerant is expanded and fed to the evaporator to complete the refrigeration cycle.

All vapour refrigeration systems, regardless of the type of compressor used, operate because of a difference in pressure which permits the collection of heat by the refrigerant at a low saturation temperature and disposal at a higher saturation temperature.

The suction vapour pressure must have a value sufficiently low so that the corresponding saturation temperature will be below the source temperature to establish the proper heat flow direction in the evaporator, likewise the discharge pressure must be sufficiently high so that the corresponding condenser temperature will exceed the temperature of the heat 'sink' to ensure the necessary rate of heat transfer.

The compressor provides the means of establishing the necessary difference between the low side and the high side pressures.

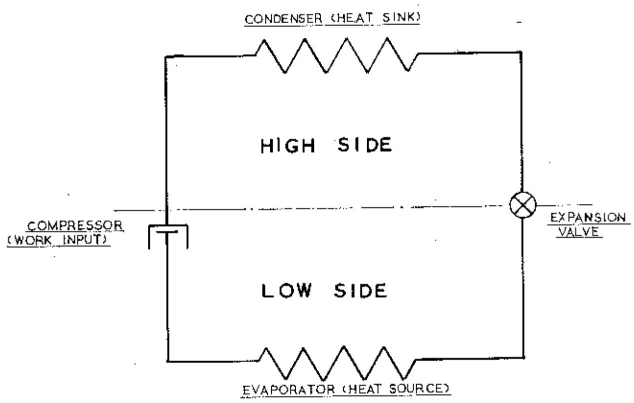


FIG 5
Basic Vapour Compression Cycle (J. & E. Hall Ltd.)

The following basic components are always found in a vapour compression cycle:- the compressor, condenser, expansion valve and evaporator.

In the refrigeration plant we are considering for grain chilling, the condenser is of the air-cooled type and the evaporator is the air cooler. The condenser consists of a series of tubes enclosed in two end plates, the tubes being provided with fins which give an extended surface and enables the equipment to be contained within a smaller space than would be the case if the tubes were just plain. An axial flow fan is fitted to the condenser which blows air through the unit to effect a greater rate of heat transfer.

The air cooling coil is designed in a similar way and is fitted to a high pressure centrifugal fan which will give the right quantity of air for the particular size of unit against the right pressure, depending on the depth of grain in store.

The compressor or compressors are usually of the totally enclosed hermetic type with the electric motor as an integral part of the compressor casing.

The expansion valve is normally of the thermostatically operated type which controls the flow of liquid to the evaporator depending upon the heat input from the source, in this case warm air.

With most refrigeration plants of this type and size the refrigerant would either be R.12 (dichlorodifluoromethane) or R.22 (monochlorodifluoromethane).

The operation of the plant for cooling air is thus as follows:

The compressor compresses the refrigerant gas and passes it to the air cooled condenser where heat is rejected to atmosphere and the refrigerant liquifies under pressure. The liquid so formed passes through the expansion valve and enters the air cooling coil where the liquid, which is now at low pressure, immediately begins to draw in heat from its surroundings, eventually vapourising at the end of its travel through the cooling coils. This vapour which is virtually 'dry' is then drawn back into the compressor and the cycle is repeated.

The outer surface of the cooling coil is surrounded by warm air which is being drawn through it by means of the circulating fan and in its passage through the coil its heat is given up to the refrigerant circulating inside the coil, and thus the air leaves the coil at a lower temperature.

During its passage through the coil the air also deposits moisture on the surface, as the dew point at the cold surface of the pipes and fins is lower than that of the dew point of the air; thus the air is reduced in temperature and also loses a certain amount of moisture. This moisture forms on the surface of the coils as a light coating of frost if the coil temperature is below freezing point; if it is above freezing point the coil surface merely becomes wet.

While the refrigeration plant is running this moisture deposition continues and a water collecting tray fitted beneath the cooling coil takes the water and allows it to drain away through a suitably designed drain connection.

It is interesting to note that if a plant cools say 2,000 ft^3 of air per minute from 72° F Dry Bulb (DB) and 62°F Wet Bulb (WB) to 50°F DB and 49°F WB the amount of moisture which will be removed by the cooling coil is approximately $2\frac{1}{2}$ gallons of water per hour.

It will be seen that under certain conditions, when the ambient temperature is low, the surface temperature of the cooling coil will be below freezing point and frosting of the coil will occur. If this frosting is allowed to continue indefinitely the coil will become completely covered with a coating of snow which will block the passage of air. To remove the snow the plant is provided with an automatic defrosting device which reverses the gas flow and temporarily makes the cooling coil into the condenser. The hot gas passing through the coil quickly melts off all the snow and after a timed interval normal refrigerant flow is resumed.

Various other methods of defrosting can be employed such as water or electric current, but for farm use the simple reverse cycle system is considered to be the most reliable and labour saving.

Grain Chilling Unit

The grain chilling unit designed for use on the farm must be robust, weather protected, easy to handle, simple and cheap to run.

For an 'on floor' system of grain chilling it is usual to have the refrigeration unit mounted on wheels so that it can be moved from duct to duct as required. As an alternative to a wheel mounted unit the plant can be mounted on a rail system to serve the same arrangement. Where a bin or silo system is considered the refrigeration plant can probably be a permanent fixture connected to permanent ducting as discussed earlier. The advantage of a mobile refrigeration plant is that it can be moved to another part of the farm where it can be used to perform another cooling duty.

The refrigeration unit would consist of one or more compressors mounted in a frame and connected to an air cooled condenser with suitable piping which would also connect to the air cooling battery as shown in Fig. 6.

In this unit it will be noted that the air cooling coil, fan and fan motor are enclosed in a plenum chamber. The air on leaving the cooler is received into the plenum chamber and the fan and motor warms the cooled air by two or three degF which reduces its relative humidity. This is a considerable help in eliminating the risk of condensation occuring at the air inlet to the grain store. It can be seen that under certain conditions moisture in the air could be deposited on the cold surface of the grain.

The refrigeration unit is completely enclosed in a sheet steel casing, louvred where necessary to provide a good air circulation for ventilation purposes, and all surfaces are weather protected. Fresh air is drawn by the fan through a suitable filter which ensures that the air entering the grain store is clean and free from large amounts of dust or other foreign matter such as weed seeds, wisps of hay etc.

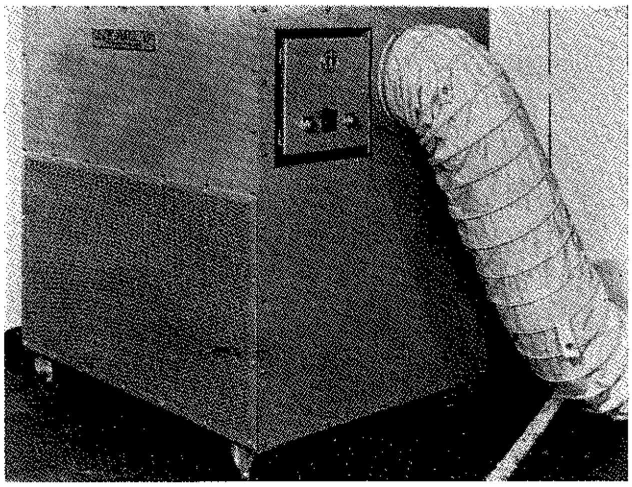


Fig. 7
Grain Chilling Unit
(J. & E. Hall Limited)

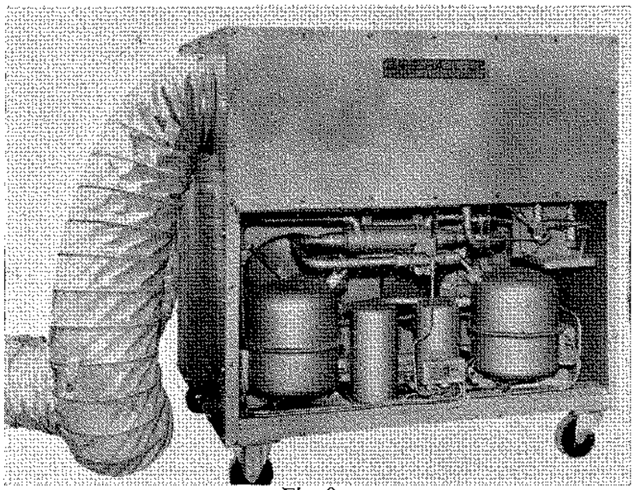


Fig. 8
Grain Chilling Unit
(J. & E. Hall Limited)

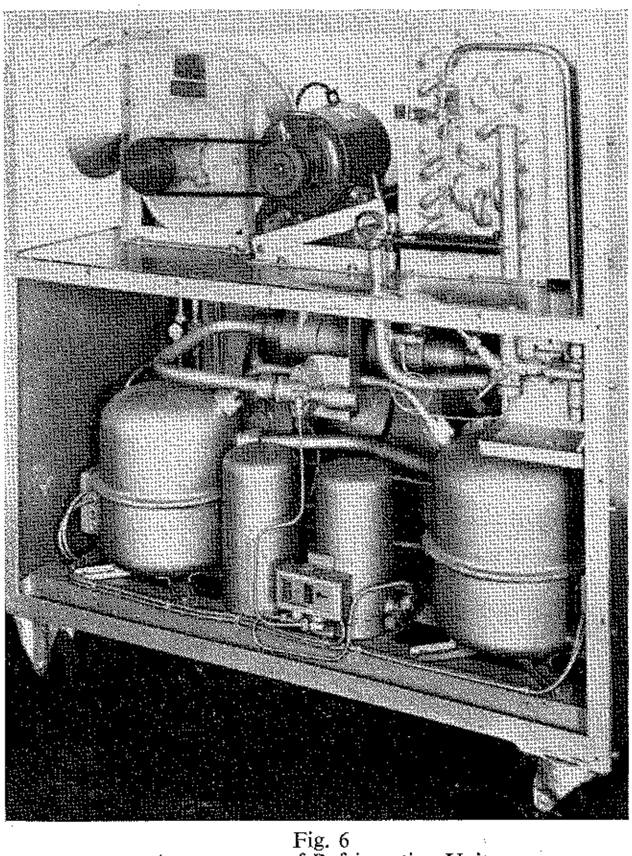


Fig. 6
Arrangement of Refrigeration Unit
(J. & E. Hall Limited)

Fan Design

The design of the grain chilling fan is of extreme importance as it must circulate the air right through the grain and discharge it at the top. The pressure drop through grain varies as to the velocity of the air passing through it and also the greater the depth, the greater is the air pressure required.

The curve in Fig. 10 shows pressure drops in an ideal bin system with the air flow linear and parallel. This may be true in very carefully controlled conditions of air flow but in most installations particularly with the 'on floor' method the air flow is anything but linear and parallel. The air takes a curving course through the grain and follows the line of least resistance. If the air encounters a particularly compacted area, possibly due to weed seeds, dust or mould, the air may by-pass this and take another route to the top, thus the resistance to flow is greater than that for an ideal system. The third curve on the chart is for barley taken from an actual 'on floor' installation and shows the difference. This curve included the pressure drop in the duct under the floor as well as through the grain itself.

The velocity of the air as it passes through the grain determines the pressure drop for every foot of depth and the greater the pressure drop the greater is the power required to drive the fan. It is therefore desirable to keep air pressures down to a minimum and therefore to design on low velocities. For all practical purposes the velocity should not be more than 6 ft^3/min per square foot of floor area.

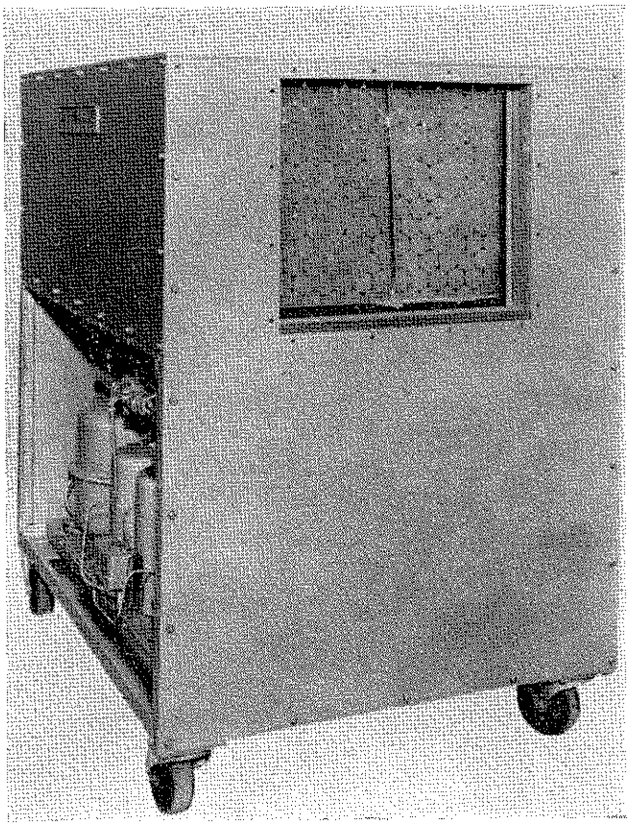


Fig. 9
Grain Chilling Unit
(J. & E. Hall Limited)

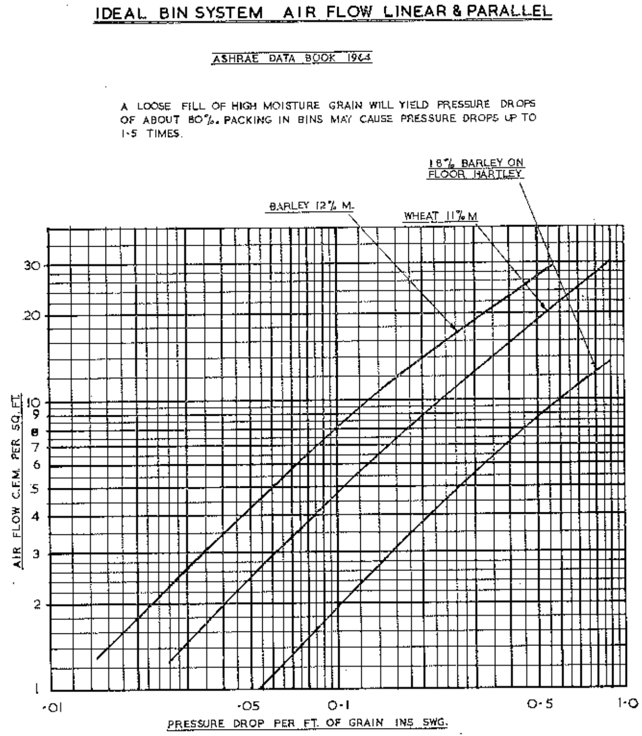


Fig. 10
Air Resistance in Wheat & Barley
(ASHRAE Data Book 1964)

It should be realised that if a centrifugal fan is designed for a given air volume against a given resistance, and the resistance is lower than the design figure, the air volume will be greater and the hp may increase, depending on the type of fan. For this reason it is important that when designing a grain chilling system the maximum and *minimum* depths of grain must be known within reasonable limits.

It is an advantage to provide a variable speed fan with at least two speeds so that any variation in depth of grain can be catered for. Alternatively a damper can be fitted to the suction or delivery side.

Electric Controls

The refrigeration plant should be controlled automatically and should be designed with an electrical starter panel capable of being coupled into the supply by means of a simple plug-in arrangement.

The control panel will contain starters for the compressor, the condenser and the grain cooling fan motors and the whole of this gear should be enclosed in one common case provided with a triple-pole interlocked isolating switch.

As the plant is intended to run for 24 hours per day it is important that it should be fitted with the necessary safety devices which will stop it in the event of breakdown or in the event of the entering air temperature falling to such a point where refrigeration is not necessary.

It is obvious that during the course of 24 hours the ambient air temperature will fluctuate considerably and there is no purpose in running the refrigeration plant if the temperature drops below 40°F (4.5°C). A simple thermostat can be fitted on the plant to stop the compressor and condenser motors when the air temperature falls to a predetermined point, but still allowing the grain chilling fan to circulate air through the system. As the air temperature rises to a higher predetermined point the refrigeration plant is allowed to start up once more.

As a further improvement, particularly on a larger refrigeration unit employing two compressors, the thermostat can be arranged to cut out one compressor when the air temperature falls to such a point where one compressor alone can do the necessary cooling.

REFRIGERATION PLANT SIZING

The rate at which heat is removed from the grain depends upon the temperature difference between the grain and the air passing through it. The larger the temperature difference the greater will be the rate of heat extraction. Because the air blown through the grain is dissipated to atmosphere and not returned to the refrigeration plant it is not possible to strike an accurate heat balance as in most refrigeration problems. A series of very complex calculations can be made which would nearly approach a balanced condition, but from experience it has been found that a more practical rule-of-thumb approach to the problem is quite satisfactory.

Consider a freshly harvested load of 50 tons of grain at a temperature of 70°F (21°C) to be cooled to 55°F (13°C). Assuming a specific heat of 0.45 Btu/lb/degF the total heat extraction required is approximately 760,000 Btu.

It has been found that the entering air temperature should be at least 5 degF below the final grain temperature, thus in this case we would require air at a temperature of 50°F. As mentioned earlier in the paper, the fan and motor add heat to the air and therefore due allowance for this must be made in calculating the plant capacity. With the size of plant under consideration the allowance we make is approximately 3 degF. Therefore the air must be cooled to 47°F in its path through the cooling coil for a final air temperature entering the grain of 50°F.

The amount of air which can be moved through the grain will be limited by its pressure drop and it is obviously desirable to work to an air veolcity which will limit the pressure drop to a figure which corresponds to a reasonable fan motor horsepower. An 'on floor' system taking a 50 ton load of grain at a height of 10 ft will occupy a floor area of approximately 250 ft^2. Taking a volume of 4.0 ft^3/min per square foot, we arrive at a total air volume of 1,000 ft^3/min. Referring to Fig. 10, the pressure drop for this velocity will be 0.21 in. SWG per foot thus for 10 ft depth the total pressure drop will be 2.1 in. SWG. To this figure must be added the pressure drop through the cooling coil and associated ducting. This latter pressure drop is rarely more than 1.5 in. SWG thus the total fan pressure for this example would be approximately 3.6 in. SWG. This figure is considered to be a reasonable one to maintain an economical fan motor horsepower.

We now make an assumption that air entering the cooling coil is at a summer day temperature of 70°F DB, 60°F WB and therefore establish a range through which the air is to be cooled. 1,000 ft^3/min reduced in temperature from 70°F to 47°F is a Sensible Heat load of 24,500 Btu/h. On the same basis it will be found that the Total Heat load is approximately 37,000 Btu/h and the plant is designed upon this figure.

The air leaving the heap will closely approach the grain temperature at the surface; this is 70°F at the start, falling during the later stages of cooling to around 55°F. For grain having a moisture content of about 20% air in equilibrium with it will have a Relative Humidity (RH) of 90 to 95%. As the air rises in temperature as it passes through the grain it will pick up moisture by evaporation, thus providing additional cooling. The quantity of moisture removed is insignificant compared with the total moisture content, being just over 0.35% in 20%.

Thus if we assume an average air leaving the grain condition of 62°F and 95% RH this corresponds to a total cooling effect of 34,500 Btu/h which if divided into the heat capacity of the grain gives an average cooling time of 22 hours.

In practice as the ambient conditions fluctuate between day and night and also from day to day the temperature entering the grain will be well below 50°F for a great deal of the time and this accelerates the cooling process. Practical results clearly shows this.

Referring to Fig. 11 it will be seen that as the ambient air temperature falls, so the air temperature leaving the cooling coil also falls and this corresponds to a gradual fall of the evaporating pressure in the cooling coil.

From the foregoing it can be seen that for 50 tons of grain the air flow required is 20 ft^3/min per ton and this figure is approximately correct for other quantities; thus 25 tons and 100 tons require 500 ft^3/min and 2,000 ft^3/min respectively.

PRACTICAL APPLICATION

In an 'on floor' system, the newly harvested grain is delivered to the farthest end of the building and, immediately one cross duct is sufficiently covered, the refrigeration plant connected to that particular duct is started up and air is blown continuously for 24 hours. After the first day's load the second and possibly the third duct will be covered with grain and it is necessary to progress to the second duct and blow for a further 24 hours. This process is repeated along the whole length of the building until harvesting is complete or the building is filled.

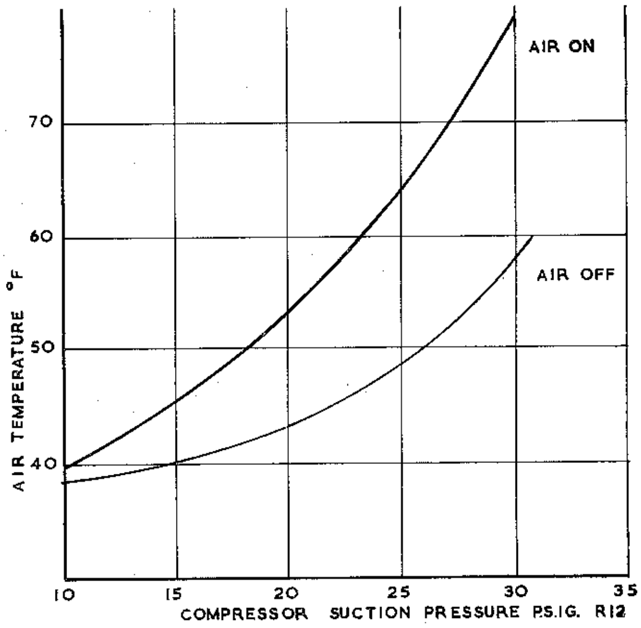


Fig. 11
Air temperature range 'on' and 'off' Refrigerating Coil
(J. & E. Hall Limited)

On completion of the blowing of the last duct the plant should be returned to the first duct to give the grain a second blow. This second blowing is necessary in order to ensure that the whole bulk of grain is reduced to the required temperature.

The diagrams shown are taken from the bulk grain store illustrated in Fig. 12. This store contained some 900 tons of barley in a building measuring 135 ft long × 30 ft wide with the barley depth at approximately 10 ft. The

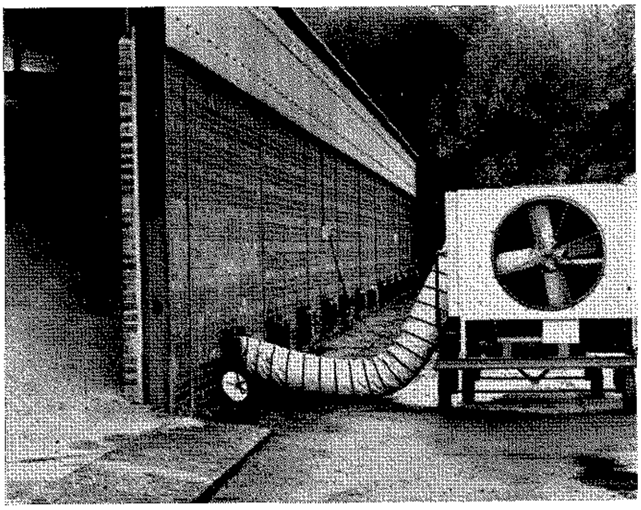


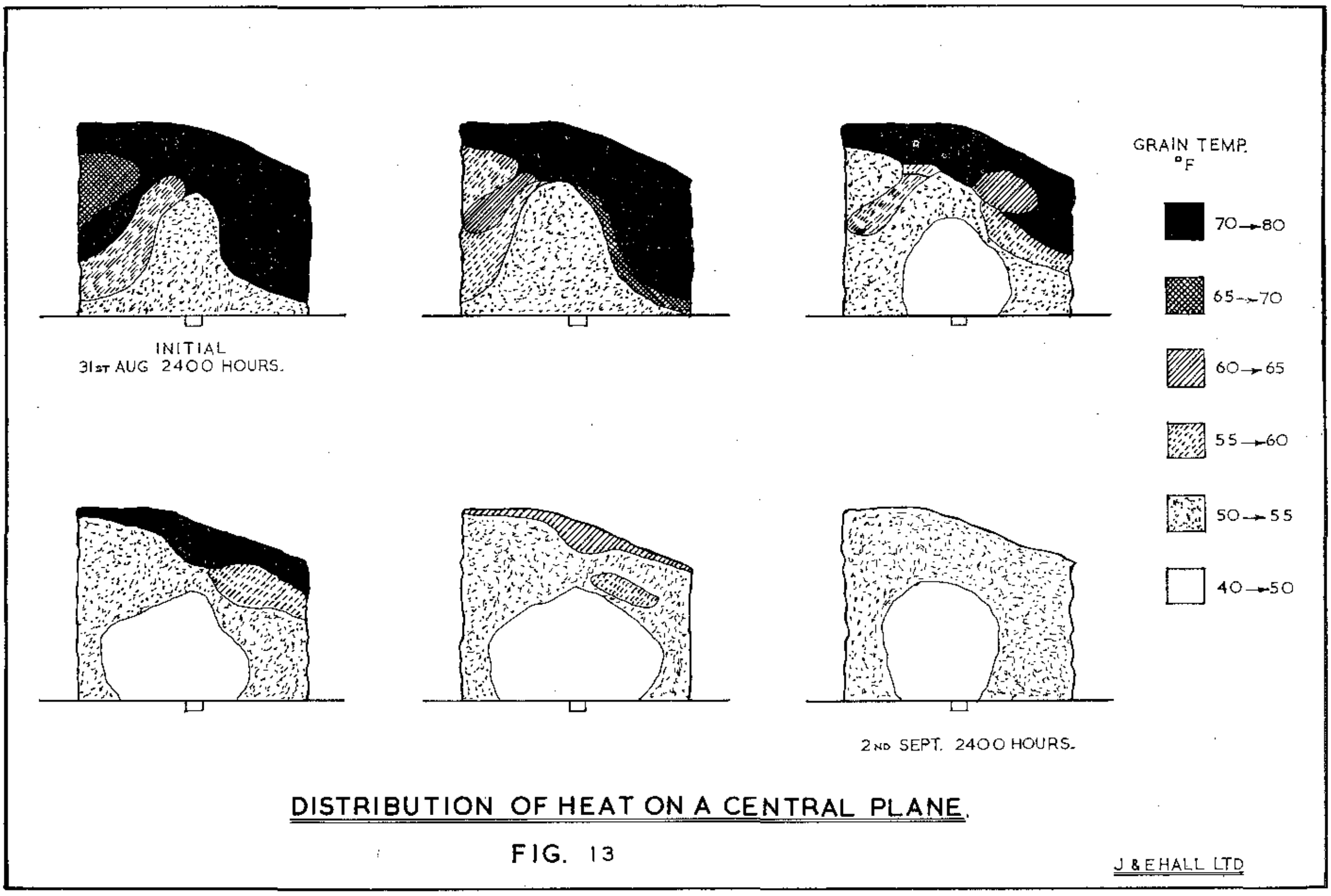
Fig. 12
Bulk Grain Store
(J. E. Hartley Limited)

floor ducts are spaced at intervals of 10 ft along the 135 ft length and each duct runs the full width of the building. The temperature readings were taken with 8 thermocouples distributed through the grain and it will be seen that the blowing period was 24 hours. During this period the maximum ambient temperature recorded was 72°F (22°C) at 12.00 hours and the minimum temperature 40°F (4.5°C) at 05.00 hours. During this period of low ambient temperature the grain fan ran alone with the refrigeration plant switched off. It should also be noted that at the start of the cooling period a proportion of the grain had already been reduced to a temperature of 55°F (13°C) where it had overflowed the duct from the neighbouring heap.

One further fact of interest is that once the bulk of grain is reduced in temperature, with the central core around the duct at a slightly lower temperature, the whole bulk gradually 'soaks' over a period of days, eventually reaching an equilibrium temperature.

It is important when dealing with large bulks of grain by the 'on floor' method to make sure that when the whole store is filled, the top surface of the grain is raked level. This ensures that the air flow passing upwards through the grain is given an approximately equal length of path to travel, thus ensuring an even distribution. If the grain were heaped high at the centre and low at the eaves the air would follow the line of least resistance and the central peak of grain would take longer to cool.

The measurement of temperature throughout the grain is of extreme importance and a thermometer mounted on



Temperature in Bulk Grain
(J. & E. Hall Ltd)

the end of a probe should be used to take readings at varying depths throughout the heap. In large installations where more elaborate and more accurate methods are preferred a complete set of distant-indicating resistance-type thermometers can be installed, terminating in a temperature indicating instrument mounted remote from the grain store.

In deep bins and similar storage vessels it would almost certainly be necessary to provide some form of fixed temperature recording or indicating instrument to check temperatures at different levels.

Temperature readings should be taken regularly to check on the development of 'hot spots' in the grain, which must be attended to immediately they are discovered. In an 'on floor' system the refrigeration plant is moved to the particular duct which would serve this 'hot spot' and the area is blown until the temperature is reduced. Similarly in a bin installation the particular bin where the 'hot spot' has developed would be blown in the same way.

REFRIGERATION PLANT SIZES

In order to cut down costs of this type of equipment manufacturers are required to build a standard range of units which would serve the farmer depending upon the size of his grain installation.

So far as can be ascertained at the moment the preference appears to be for a small to medium-sized plant capable of chilling between 15 and 50 tons of grain at a time. There also appears to be a case for manufacturers to consider making an even smaller unit of say 10 tons, but it may be found that the capital cost of this would not be attractive.

TABLE I

Plant Size	*Compressor Motor hp*	*Condenser Fan Motor hp*	*Chilling Fan Motor hp*	*Total hp*
15	$1\frac{1}{2}$	$\frac{1}{10}$	$\frac{1}{2}$	$2\frac{1}{10}$
25	2	$\frac{1}{6}$	1	$3\frac{1}{6}$
50	4	$\frac{1}{2}$	2	$6\frac{1}{2}$
100	6	1	5	12

In some large installations it is necessary to design for a 100-ton grain chilling plant and it would therefore be reasonable to suppose that a standard range should be manufactured for 15, 25, 50 and 100 tons per day capacity.

In terms of connected hp the following figures will be of interest:

It will be seen from Table 1 that if the power of the chilling plants is expressed in terms of tons of grain per horse power, the figure is approximately 8.0 ton/hp varying a very few per cent either way.

The following table gives the cost of running these chilling plants assuming $1\frac{1}{2}$d per unit of electricity.

TABLE II

Plant Size	*Total hp*	*kW*	*Running cost Pence per hour*
15	$2\frac{1}{10}$	1.56	$2\frac{1}{2}$
25	$3\frac{1}{6}$	2.35	$3\frac{1}{2}$
50	$6\frac{1}{2}$	4.85	$7\frac{1}{4}$
100	12	9.0	$13\frac{1}{2}$

CONCLUSION

This paper has attempted to cover present-day practice in the chilling of grain. It must be remembered that this particular application of refrigeration is comparatively new and there is still a considerable amount of research to be done on the behaviour of grain when stored at this low temperature. At the moment it appears that the greatest application for this method is where a farmer is using the grain for feeding. There are however indications that millers are interested in holding large quantities of grain at low temperature, drawing from store as and when they require it for drying. By this means the miller can keep the drying operation under his own control.

There is no doubt that as farms are modernized, new techniques are developed and the preservation of food at source is further extended, the Refrigeration Engineer in co-operation with the Agricultural Engineer can contribute a great deal to this progress.

As interest in refrigeration on the farm grows there may be a case for designing one refrigeration unit, suitably sized to handle many different applications over the farming year.

Charlie / From experience you could do all this with a small fan on a cold or frosty night - !!

DISCUSSION

Mr I. R. Rutherford (Shropshire Education Committee) enquired about the economics of having a lower evaporation temperature with defrosting equipment on the one hand compared to having a higher evaporation temperature and managing without defrosting equipment. Was it essential to have this sophisticated equipment? Mr Rutherford further asked whether one needed this equipment in duplicate. Mr Munday said he must refute the suggestion that it was a complicated system; he did not believe there was anything complicated about an automatic defrosting system. The reverse cycle defrosting system was reasonably simple and foolproof and not unduly expensive. He felt that this was definitely the right approach to the problem rather than the alternative of running a plant at a higher temperature. If air entered the coil at 45°F it would still require cooling a little and one would have to employ a very large air-cooling coil in order to do this because the temperature difference between the evaporation temperature and the air leaving temperature is inversely proportional to the cooling surface. The smaller the temperature difference the greater the surface. To maintain a surface temperature above freezing the evaporation temperature would have to be no lower than 30°F at any time. Another important reason for maintaining a reasonably large temperature difference between air and evaporation is to remove as much moisture as possible from the air before it enters the grain, and in this case the amount of moisture removal is directly proportional to the temperature difference, air to evaporation. The advantage of using two compressors is that on low duties and with low ambient conditions it is possible to run with one compressor, thereby affecting a saving in hp. One of the compressors could be arranged to operate with a thermostat such that when the ambient temperature falls to a predetermined point the compressor is shut off automatically, and is allowed to start up again when the temperature rises.

Mr W. G. Cover (Simplex Dairy Equipment Co Ltd) said it was appreciated that the systems described were a comparatively new application of chilling of grain but in order that the matter could be seen in its correct perspective could Mr Munday state over how many years his experience of chilling of grain had been based and in relation to how many installations. Secondly, he asked for some indication of the economics involved, with particular regard to running costs and bearing in mind that the conditions would vary considerably from one harvest to another. Mr Cover went on to say that on reading the paper he had understood that the air should be cooled to a temperature of about 55°F and yet from the discussion he had gained the impression that it would be wiser to take it to a much lower figure, possibly in the region of 40°F to 45°F. Bearing in mind that Mr Munday's paper referred to plants having capacities of 45, 25, 50 and 100 tons per day, he asked how these would be affected by the lower temperature requirement. Mr Munday replied that experience of this kind had been gained over three years with five installations; in the current year a further eight or nine would be installed. He did not know the total number of refrigerated grain stores in the country, but he believed there must be some 30 or 40. As an example of the economics of refrigerated grain storage from the figures in his paper it could be seen that the running cost of a 50 ton per day unit could be around 7¼d per hour, based on an electricity cost of 1½d per unit. If there were 500 tons in store one would blow 24 hours per day for 10 days and the cost would then be £7 5s. Allowing for three 10-day chilling periods during the total storage period the cost would be £21.15s. giving a cost per ton of grain in store of 10½d. With 1,000 tons in store and using a 100 ton per day unit the cost would work out at a little under 10d per ton of grain in store. Mr Munday pointed out that one must further take into account interest on the capital and depreciation; this when added to the running cost would result in a total figure of around 6s. per ton per annum. The question of temperature had next to be considered and if grain was to be cooled from maximum day temperatures of 70° to 75°F and a minimum night temperature of about 45° the probability was that the grain would be cooled to nearer 50° than 55°F even if it had to be blown twice, which should probably be done in any case. If it was desired to cool it somewhat lower, this could be easily done, but one would probably reduce the tonnage per day that could be handled, possibly by about 10%; thus instead of its being a 50 ton per day unit, it would become a 45 ton per day unit. Once grain had been reduced to a safe temperature level it would hold at 50°-55°F and then it would be possible to return to it two or three times if necessary to reduce the temperature still further, by blowing at night only.

Mr R. J. Sims (Surrey Farm Institute) asked Mr Munday if he could give some idea of the capital costs of refrigeration plant. Mr Munday replied that the capital cost of a 15 ton per day unit was about £650, 25 ton per day £720; 50 ton per day about £900; and 100 ton per day about £1,450. These were plants which were complete in every way with automatic defrosting and all that was necessary was to plug into the electricity supply which could be 3-phase or single-phase.

APPOINTMENTS SERVICE

Members are cordially reminded that a monthly list of situations vacant in the agricultural engineering industry, teaching and research, both in Great Britain and overseas, will be supplied on request.

Those wishing to avail themselves of this service should notify the Institution Secretary. It would be appreciated if members would inform the Institution of changes of appointment, in order that office records may be kept up to date and, where applicable, the circulation of lists from the Appointments Service terminated.

INSTITUTION TIE

As announced in previous issues of the *Journal*, Institution ties are available, incorporating the design of the Presidential Badge on either dark-blue, dark-green or dark-red grounds. These attractive emblems may be purchased and worn by members only; they are available in any quantity at a cost of 15/- each, which charge includes packing and postage.

Order forms may be obtained from the Institution Secretary.

PRINCIPLES OF WET GRAIN CONSERVATION

by MARY B. HYDE, M SC,M I BIOL*

A Paper presented at the Annual Conference of the Institution in London on 22 *April* 1965

SUMMARY

The general principles affecting grain preservation are discussed. The external factors, moisture, temperature and supply of oxygen that influence the development of moulds and insect pests are considered in relation to the biological and physical properties of the grain itself (respiration, hygroscopic and thermal properties) which affect its storage potential.

These characteristics are discussed in relation to the conservation of high moisture grain by chilling with refrigerated air or by airtight storage in sealed containers.

A brief account is given of some experiments on airtight storage.

INTRODUCTION

One of the main reasons why cereal grains have become the staple food of so many nations is because they can be stored safely for long periods, and so be used throughout the year, in contrast to more perishable foods, which have only seasonal use.

In order that they can be stored safely, cereal grains must be dried on harvest to a low moisture content, for moulds will develop rapidly if the crop is too damp when put into store.

For many purposes, however, the grain is not used in a dry form. Indeed, for some uses, e.g. flour milling, the moisture content has to be raised before processing. In malting, also, water is added on steeping. Recent developments in animal feeding have shown the nutritional advantages of rolling barley, as opposed to grinding, and for such rolling it is necessary to moisten the grain, if it has been dried for storage.

Farmers and others have begun to ask: why dry grain, to have to wet it again? Why indeed, if it can be stored satisfactorily in the wet state?

With certain limitations, grain can be stored in the wet state, either by airtight storage in sealed silos or by chilling with refrigerated air. The grain so stored, however, is seldom suitable for all purposes, and these methods cannot be regarded as an alternative to drying. Drying will always have its place in the farming world, at least in the foreseeable future.

In many countries the climate at the time of harvest of the grain crop is not dry enough for natural drying to be effective, and the grain must be dried artificially.

Previous speakers have already dealt with the subject of artificial drying. The object of the present paper is to describe the principles underlying the safe storage of high moisture grain. To understand these, some more general principles, relating to grain storage generally, must first be established.

* Agricultural Research Council Pest Infestation Laboratory, Slough, Bucks.

EXTERNAL FACTORS AFFECTING STORAGE

The harmful organisms (insects and mites, moulds and bacteria) that attack stored grain are influenced primarily by three factors:

(*a*) moisture
(*b*) temperature
(*c*) oxygen.

(*a*) Moisture

Development of moulds, bacteria and 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, for they all need moisture for their growth. This, as mentioned earlier, is the normal method of making grain safe to store. Generally, drying to a moisture content of about 14 per cent will limit the development of moulds, bacteria or mites, but for insects the low moisture level required to restrict growth (8-10 per cent) is uneconomic to attain, and maintain, in practice.

(*b*) Temperature

Like all living organisms, insects and moulds need a reasonable temperature if they are to grow at all quickly.

Insects will not develop readily if the temperature is below 17°C (63°F) and cooling dry grain to this level, and keeping it cool, is a satisfactory means of preventing infestation by many species of stored product insects. This degree of cooling can be achieved by ventilating with normal, untreated air. To control moulds, bacteria and mites, however, the temperature must be much lower, depending on the moisture content of the grain. For moisture contents up to about 20-22 per cent, chilling to about 5°C (41°F) is necessary. At higher moisture levels the temperature must be near freezing point if damage by moulds and mites is to be prevented.

As well as inhibiting harmful organisms, low temperature also enhances the keeping quality of the grain and enables the germination capacity to be maintained, even at relatively high moisture levels (20 per cent, if chilling is to 5°C (41°F)).

The temperature to which the grain must be chilled depends to some extent on the time it is to be kept in store, but adverse changes cannot be warded off indefinitely at economically obtainable temperatures, at high moisture contents.

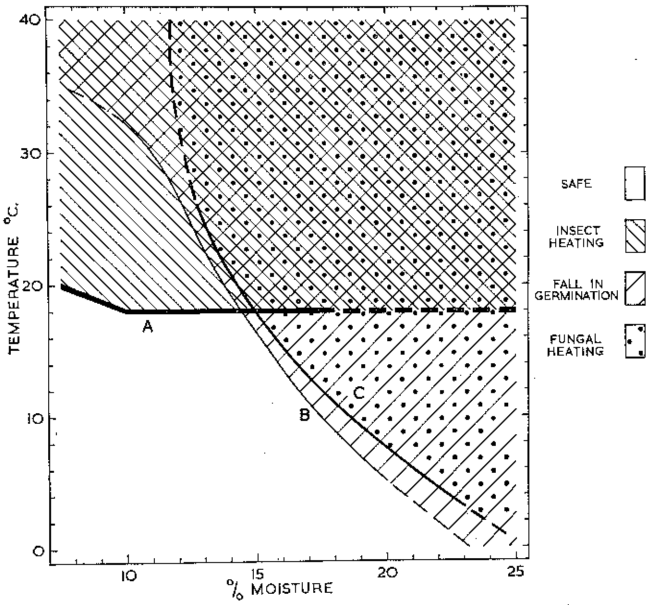


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Fig. 1

Relation of storage temperature and grain moisture content to insect heating, fall in germination (to 95% in 35 weeks storage) and damp grain (fungal) heating.

Figure 1 shows the relationship between temperature and moisture content in relation to keeping quality. It was compiled from a large number of sources, and represents 'pessimistic' rather than average values.

Thus, at moisture contents up to about 22 per cent, grain can be stored safely for a reasonable time at temperatures of 5°C (41°F) or below, which can be obtained by refrigeration (chilling).

(c) Oxygen

Oxygen is the third of the external factors that affect the pests attacking stored grain. Insects, mites and moulds all need air for their growth and can be controlled by exclusion of oxygen, i.e. by airtight storage. The insects, mites or moulds use up the oxygen in the airtight container and thus kill themselves before they have become numerous enough to cause damage.

Inter-relation of External Factors

These three factors, moisture, temperature and oxygen, are all inter-related. Development of moulds and insects in grain, and their control, can be related to three different levels of moisture content, as follows:

	Moisture Content of the Grain	*Insects and Micro-organisms controlled by*
(*i*)	Up to 15 per cent	Low moisture content; cooling with untreated air
(*ii*)	15 to 25 per cent	Drying; refrigeration (only up to 20-22 per cent moisture content); ordinary airtight storage
(*iii*)	30 to 40 per cent	'Silage' techniques (and unstable form of airtight storage)

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

PROPERTIES OF GRAIN THAT AFFECT STORAGE

So far, the external factors affecting storage of grain have been discussed. There are also certain properties of the grain itself which have to be considered.

(a) Grain is a living organism

Grain is alive, and therefore respiring, thereby producing heat, carbon dioxide and water. In dry, uninfested grain the rate of respiration is very slow. It is much more rapid, however, in grain which is infested by insects or mites, or is damp and mouldy. In such circumstances the amount of heat and water produced can lead to serious damage to the grain.

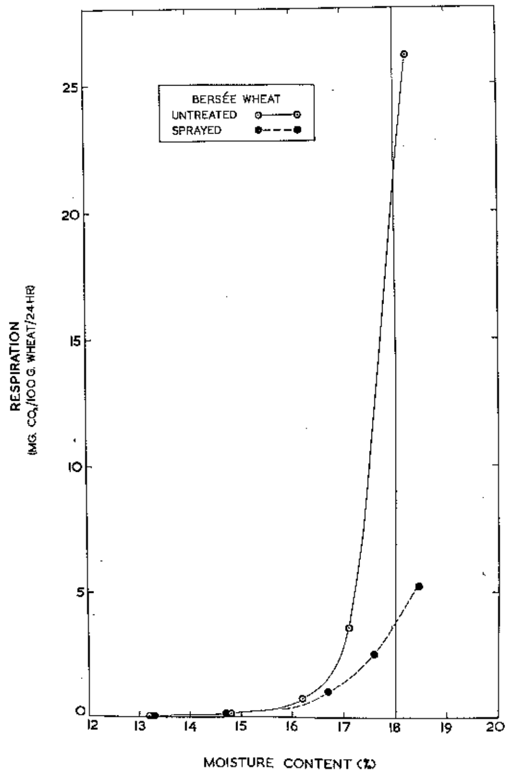

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Fig 2

Respiration of normal and fungus-free wheat, in relation to moisture content.

Figure 2 shows the results of some experiments at the Pest Infestation Laboratory on English wheat, on the rate of respiration (carbon dioxide production) at various moisture contents. In grain that had been sprayed during development in the ear with a fungistatic substance, and which was free from moulds, the rate of respiration increased relatively slightly with increasing moisture content. In untreated grain, on the other hand, the rate of respiration rose sharply at moisture contents above 16 per cent, and this increase was associated with the growth of moulds. In damp grain, therefore, it is the moulds that are primarily responsible for production of heat, and not the grain itself.

It may perhaps be mentioned, in passing, that living grains are less likely to be attacked by moulds than are dead ones, which are very susceptible to mould attack. Also cracked, broken grains are more easily attacked than are sound, whole ones.

The respiration of an insect infestation depends on the density of the population of insects. Figure 3 shows the rate of consumption of oxygen by the Grain weevil (*Sitophilus granarius*) in an airtight container at two different levels of population (18 and 180 adult insects per pound of grain). When all the oxygen had been used up, the insects died.

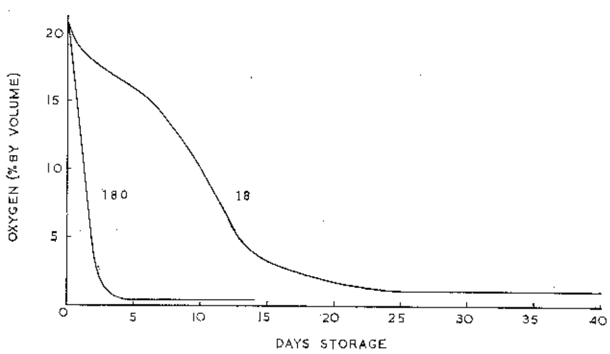

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Fig. 3

Utilization of oxygen by two populations of *Sitophilus granarius* in airtight containers.

The respiration, either of insects or moulds, is accompanied by production of heat, which, if the infestation or moulding is severe, may result in the development of 'hot spots' in the grain. Insects can raise the temperature of the grain to 40-45°C (105-110°F) before the temperature is too high to prevent their further development. With moulds, the temperature can rise to 60-70°C (140-160°F) before self-sterilization sets in.

Because of the production of moisture during the heating, a hot spot caused originally by insects in dry grain will sometimes develop secondarily into damp grain heating, due to the subsequent development of moulds on the dampened grain.

(*b*) **Grain is a hygroscopic material**

Grain and other foodstuffs are hygroscopic materials which will absorb or give up moisture until they are in equilibrium with the surrounding air. The actual relationship depends on the type of food-stuff. In starchy materials such as cereal grains the equilibrium moisture content at a given relative humidity of the air is higher than with a more oily product (Figure 4).

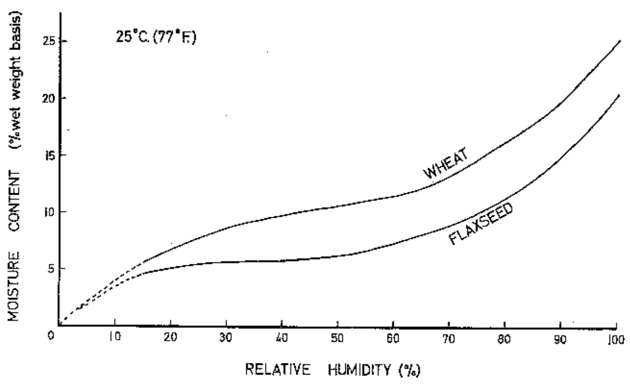

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Fig. 4

Relationship between moisture content and relative humidity of wheat and flaxseed.

The equilibrium moisture content is slightly different according to whether the material is absorbing or giving up moisture, i.e., there is a hysteresis effect. An example is given in Figure 5.

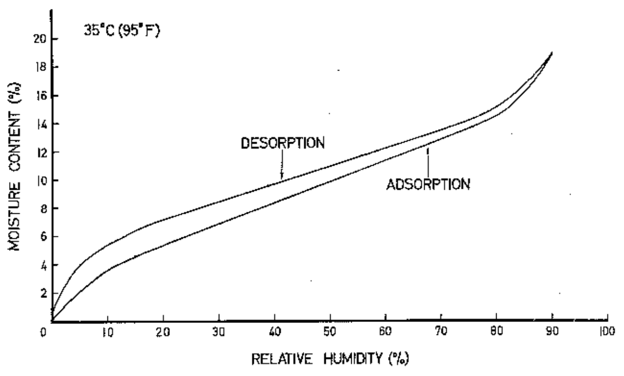

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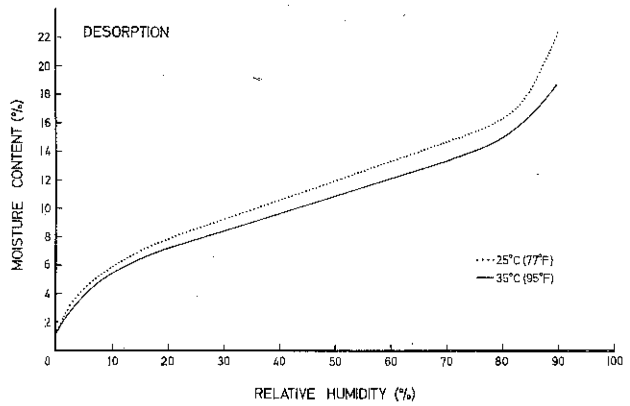
Fig. 5

Adsorption and desorption isotherms for wheat at 35°C.

There is also a slight difference in the equilibrium at different temperatures. A rise in temperature lowers the moisture content at a given relative humidity. In cerea grains the equilibrium moisture content is lowered by about 0.6 per cent for each 10 deg C (18 deg F) rise in temperature. An example is given in Figure 6.



Reproduced by courtesy of J. E. Hubbard *et al.* (1957)

Fig. 6

Desorption isotherms for wheat at 25°C and 35°C.

This is not significant in temperate countries, but may become important in the tropics, where the safe moisture content must be correspondingly reduced, particularly as the higher temperature will increase the rate of development of the pests.

Small quantities of grain exposed to air will come into equilibrium with it in a relatively short time, but in bulks of grain inequalities in moisture content will take a surprisingly long time to 'even out'. It is quite wrong to assume that a batch of high moisture grain in a bulk will soon reach the same moisture level as the rest. For example, some experiments at the Pest Infestation Laboratory currently in progress are indicating that a pocket of high moisture grain (22.1 per cent) in a mass of drier grain (13.7 per cent) still has a higher moisture content after 142 days' storage at two different temperatures, 5°C (41°F) and 22.5°C (72.5°F) (See Figure 7). At the higher temperature the grain seems to have reached a steady state, and the difference (approximately 0.5 per cent moisture content) between the originally wet and dry grain is undoubtedly a hysteresis effect.

This test is being carried out in a closed container under static conditions, and the exchange of moisture is entirely by diffusion. In actual bulks of grain, there would inevitably be some movement of air producing convection currents which would increase the rate of exchange of moisture. In stacks of bagged grain air movement would be greater still, but even so, any bags of wet grain would remain a hazard for a long time.

On the whole, a wet bulk of grain will remain wet, and a dry bulk will remain dry, except at the periphery, where exposed to the air. Here, it will come into equilibrium with the humidity of the atmosphere, as described earlier.

Although it is usual to regard the moisture content of the grain as the factor limiting mould growth, it is really the relative humidity of the air that is decisive. Most moulds will not grow at all readily at relative humidities below 75 per cent, although a few species can grow at 70 per cent. As an example, Figure 8 gives some data obtained at the Pest Infestation Laboratory on the growth rates of a storage mould, *Aspergillus repens*, whose development is much restricted below 75 per cent relative humidity.

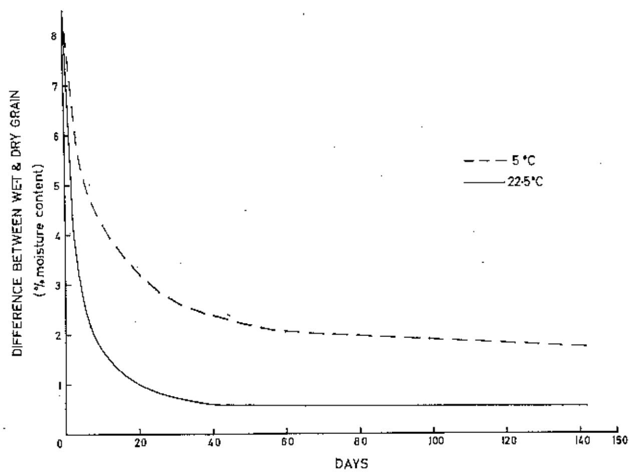


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Fig. 7

Rate of interchange of moisture between grain at 22.1 and 13.7 per cent moisture content.

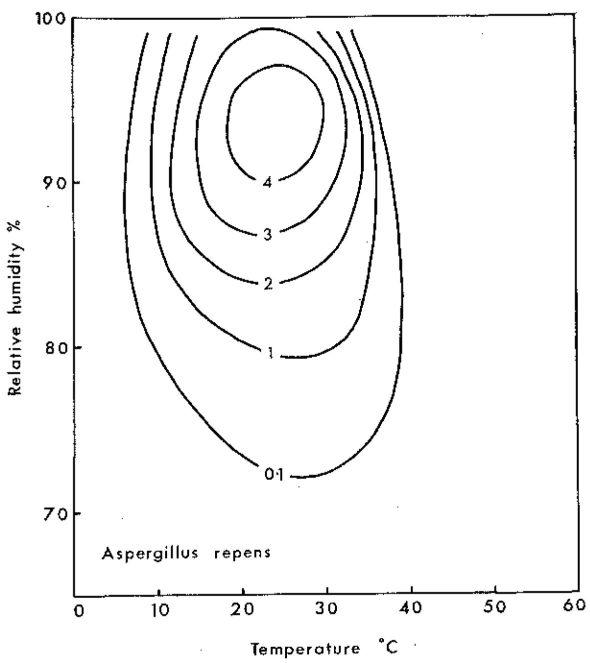

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Fig. 8

Growth rates (mm/day) of *Aspergillus repens* on wort agar, in relation to temperature and relative humidity of the atmosphere.

Because of the equilibrium relationship between grain moisture content and atmospheric humidity, and because it is generally more difficult to measure humidity than it is to determine moisture content, the latter is usually taken as the criterion for safe storage, and one tends to speak of a 'safe' moisture content rather than a 'safe' relative humidity. But this is really the controlling factor, and, for this reason, the 'safe' moisture content varies in different products. For cereal grains it is about 14 per cent, corresponding to a relative humidity of rather less than 70 per cent.

(*c*) Grain is a poor conductor of heat

Being a granular material, grain is a poor conductor of heat. Heat will be conducted from one grain particle to another only where they touch, and will be radiated across the intergranular air. There may also, in some circumstances, be mass movement of this intergranular air, transferring heat more quickly, by convection. This is only likely to occur when there are temperature gradients in the grain, i.e., differences in temperature between one part of the grain bulk and another.

The thermal conductivity of various grains has been determined by a number of workers, whose results are in general agreement. The figures given in Table 1 were determined at the Pest Infestation Laboratory some years ago by T. A. Oxley. Values for granular cork (an insulating material) and concrete are given for comparison.

TABLE 1

Thermal Conductivity of various Ceareal Grains
[From T. A. Oxley (1944)]

Material	*Moisture Content (%)*	*Thermal Conductivity (C.G.S. units)*
English wheat	17.8	0.00039
Manitoba Wheat	11.7	0.00036
Yellow Maize	13.2	0.00042
English Oats	12.7	0.00031
Granular cork	—	0.00012
Concrete	—	ca. 0.004

As grain is usually stored in fairly large bulks, although it is not as good an insulator as a material such as cork, the greater thickness involved will effectively reduce the uptake or loss of heat at the centre of the grain bulk.

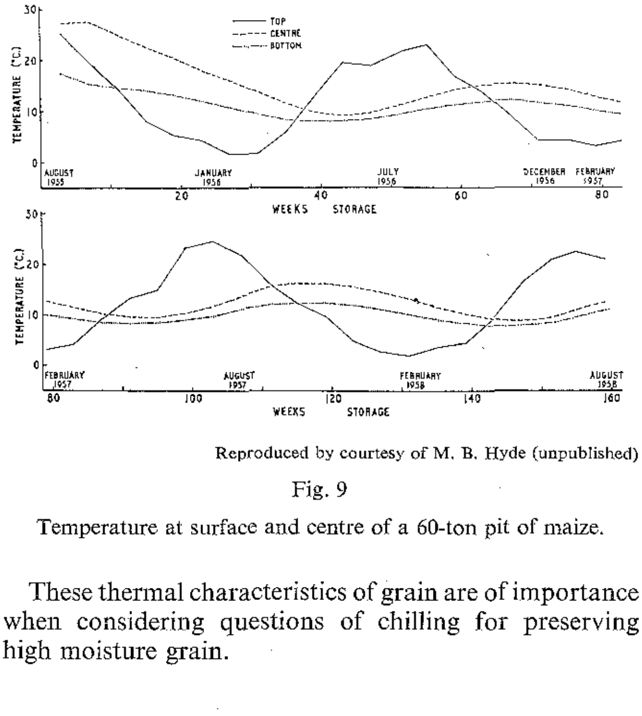
Therefore, except at the periphery, once it is warm, a grain mass will remain warm, and once cool, it will stay cool, assuming there is no insect or mould growth, unless there is induced movement of air to cause transfer of heat by forced ventilation currents. This ability to retain heat or cold can be important in practice.

The response of a grain bulk to external fluctuations of temperature will vary with the extent of the external fluctuation. Slight, short-term changes in temperature will only extend a few inches into the grain, but long-term fluctuations will gradually be passed on to the interior of the bulk.

For example, studies by Babbitt (1945) have shown that a diurnal fluctuation in temperature of 11 deg C (20 deg F) will cause a change of 0.55 deg C (1 deg F) at a distance in the grain of 5 in. With an annual fluctuation of the same amount, the same change will be produced further in the bulk, at a distance of 9 ft from the surface.

There is also a delay in the penetration of heat or cold from outside, which can be up to 3 months at a depth of 5½ ft, although the surface grain will respond immediately to any temperature change.

Figure 9 gives some results for the temperature at the surface and the centre (6 ft down) of a 60-ton pit of maize at the Pest Infestation Laboratory, over several seasons. Not only was there a delay of about 3 months in the time of maximum and minimum temperature at the centre, compared with the surface, but the range was much reduced, the annual range at the centre being only about 6 deg C (10 deg F) compared with 22 deg C (40 deg F) at the surface, just below the roofing felt cover.



Reproduced by courtesy of M. B. Hyde (unpublished)

Fig. 9

Temperature at surface and centre of a 60-ton pit of maize.

These thermal characteristics of grain are of importance when considering questions of chilling for preserving high moisture grain.

Applying Principles to Practice

We may summarize the factors necessary for safe storage of grain as

low moisture content,
low temperature,
low atmospheric oxygen.

If one eliminates the first of these, low moisture content, i.e., if one is storing high moisture grain, one is left with

low temperature,
low oxygen.

These are, in fact, the two methods of preserving high moisture grain, i.e., by chilling with refrigerated air or by storing under airtight conditions in sealed containers.

Mr Munday will be describing the use of chilling for wet grain conservation, and Mr Culpin will be dealing with the practical applications of airtight storage. I should like to end this paper by giving some account of the more fundamental aspects of airtight storage, based on studies carried out at the Pest Infestation Laboratory over the past thirteen years.

AIRTIGHT STORAGE

The modern use of airtight storage for high moisture grain stems from experiments in France in 1938 by Blanc in specially constructed welded steel bins, and more recent developments in the United States using the so-called 'glass-lined' steel bins originally intended for silage.

In France the moisture content of the grain stored in airtight bins is fairly low, usually about 17 per cent, and it rarely exceeds 21 per cent. This grain is used for milling, as well as for animal feed. In this country and in America, however, the grain is of much higher moisture content, often up to 25 per cent. Because of the changes that take place in the grain at this moisture level, it is only suitable for animal feed.

With the increasing use of rolled barley for feeding to cattle, especially for barley beef, the method has become quite extensively used in the past few years on farms in Britain, and the development seems likely to continue.

Tests carried out at the Pest Infestation Laboratory since 1952 in containers ranging from 2 lb cans to 10 ton bins have enabled a general picture of the changes taking place during airtight storage to be obtained. The laboratory findings have been confirmed by subsequent experience in practice.

Appearance of the Grain

As long as the bin is airtight, hermetically stored grain remains bright in colour and flows freely, even at relatively high moisture contents (22-24 per cent). At moisture contents above 17 per cent there is a certain amount of fermentation, and the grain develops a characteristic sour-sweet smell and bitter taste, not always removed by subsequent airing or drying. Above 25 per cent moisture content the grains may become dark in colour and rather soft. No mould growth is seen on grain from a properly airtight bin, and the number of viable mould particles on the grain decreases with time.

Table 2 gives the results of some tests at the Pest Infestation Laboratory on the survival periods of several different mould fungi, on grain of 24 per cent moisture content stored in airtight containers at the temperatures shown.

TABLE 2

Genus	*Time (weeks) for viable mould count to fall to 1 per cent of the original*		
	25°C	15°C	5°C
Penicillium	10	27	37
Cephalosporium	1	2	11
Cladosporium	0.5	1	3

[From D. Budd (1959)]

If the containers are not completely airtight, certain organisms, such as mycelial yeats, will develop and give a mouldy appearance to the grain.

Chemical Changes in the Grain

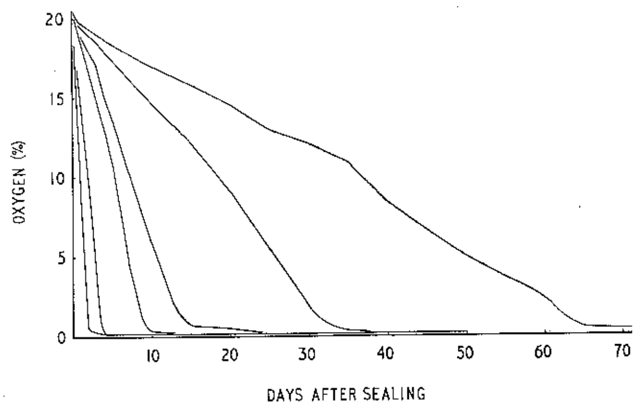
During airtight storage certain chemical changes take place which affect the future use of the grain. In wheat, changes in the gluten and amount of sugar are sufficient to damage its milling and baking properties. There is deterioration in the quality of the dough, and the crumb of the bread is dark and close in texture, so that the loaf volume is reduced. The effect of these changes is lost when the grain is mixed with a high proportion of normally stored wheat, but even so airtight storage cannot be considered for high-moisture wheat intended for milling.

As far as is known, the changes that take place in the grain are not harmful to livestock, and it can be fed satisfactorily to cattle, sheep and pigs. The grain is readily accepted by the stock. Indeed, some users claim increased palatability, and better conversion ratios, especially at high moisture levels (over 25 per cent). Information on this matter is still somewhat inconclusive, and further investigations are necessary on the chemical, micro-biological and nutritional aspects of airtight storage.

Changes in the Intergranular Atmosphere

As explained earlier, the moulds that grow on damp grain must have a supply of oxygen, and in a sealed container they soon use up the oxygen originally present and cease to grow when the oxygen is exhausted.

The rate at which oxygen is used up and carbon dioxide is produced depends mainly on the moisture content of the grain. At moisture contents of 22 per cent and above, all the oxygen is utilised in a few days. (Figure 10).

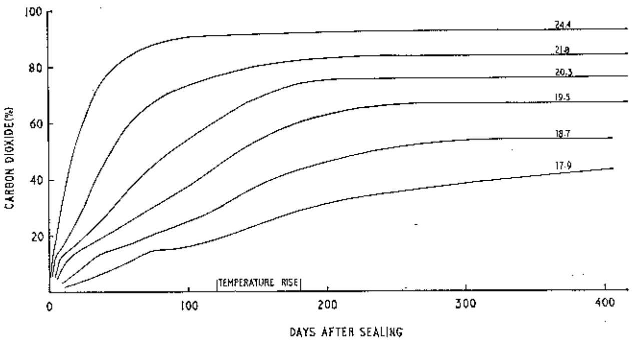


Reproduced by courtesy of M. B. Hyde and T. A. Oxley (1960)

Fig. 10

Utilization of oxygen by grain of different moisture contents, in sealed containers. The curve from left to right show moisture contents of 24.4, 21.8, 20.3, 19.5, 18.7 to 17.9 per cent.

With grain at moisture contents over 15 per cent carbon dioxide is produced in excess of the oxygen used up, due to respiration by organisms able to flourish in the absence of oxygen, so-called anaerobes (Figure 11).



Reproduced by courtesy of M. B. Hyde and T. A. Oxley (1960)

Fig. 11

Production of carbon dioxide by grain of different moisture contents, in sealed containers.

The build-up of carbon dioxide causes excess pressure which is released in commercial bins by a pressure release valve, or compensated by a 'breather bag'. The air that escapes consists of carbon dioxide and nitrogen. The further production of carbon dioxide can result in an atmospheric containing as much as 95 per cent of this gas. It has often been suggested that the anaerobic fermentation could be prevented, or at least reduced, by adding carbon dioxide at the time of filling, Our own investigations and those of others indicate that this is not so, and that added carbon dioxide does not appreciably reduce the fermentation and its effects. At present, therefore, it is felt that it is not necessary to add nitrogen, carbon dioxide or other inert gas. One of the main virtues of airtight storage is its simplicity, and it is best to let it remain so.

Effect on Germination

One effect of removing the oxygen, together with the high moisture content, is to lower the germinative capacity of the grain, thus making it unsuitable for malting or seed purposes. Generally, the viability remains reasonably high for some time, and then it falls rather suddenly to a low level. The rate at which the reduction takes place depends on the moisture content and temperature of the grain. (Table 3 & Figure 12)

TABLE 3

Decrease in Germination in Hermetically stored Grain

Moisture Content	*Decline began after*
(%)	(weeks)
14	>105
17	60
19	30
20	10
23	5
24	2

[M. B. Hyde (unpublished)]

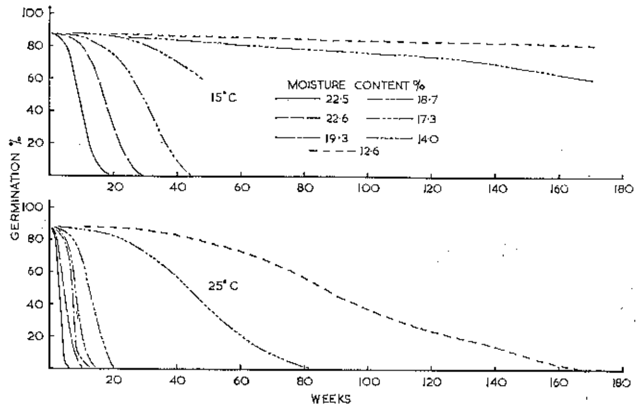


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Fig. 12

Effect of moisture content and temperature on germination of grain in sealed containers.

Storage in Non-airtight Containers

So far I have spoken of storage in completely airtight containers, whose behaviour is assured as long as they are properly managed and maintained.

What about storage of wet grain in bins that are not completely airtight, e.g., concrete stave silos?

The success obtained by the one or two farmers using such bins is probably due to the grain being of very high moisture content (over 30 per cent). It would be very unwise to use such bins at moisture levels much lower than this. It seems probable that we can regard these non-airtight bins as providing an 'unstable' oxygen-free condition. The grain at the top surface uses up the oxygen in the air above and, being very soft, compacts to form a firm layer, or crust, which effectively excludes air from the grain below. Provided the walls of the bin are reasonably airtight, the main mass of grain will then be in an atmosphere consisting largely of carbon dioxide, which, being heavier than air, will remain in the bin when the top layer of grain is removed. These bins are always unloaded from the top, and each successively exposed layer will use up most of the oxygen getting in and be removed in its turn before it has time to become visibly mouldy.

The principles of this type of storage are however still hypothetical, and any storage of high moisture grain in non-airtight bins must at present be regarded as experimental.

But these and other experiments will and must continue. There is no doubt that the storage of high moisture grain on British farms is increasing, and chilling and airtight storage have come to stay.

Practices that were thought impossible only a few years ago are now accepted as commonplace, and the queries at present existing may soon be answered by research and practical experience. There is still a lot to learn, especially about the nutritional value of the grain, and there are still unloading and other mechanical problems to overcome—a challenge surely to this Institution, above all others!

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DISCUSSION

Captain L. R. Bomford (Bomford Bros Ltd) said that although Miss Hyde had used the term 'grain' throughout her paper, he took it that wheat, barley and oats were roughly similar for this purpose. He asked if grass seeds behaved in the same way. Miss Hyde replied that she had used the word grain because she was basically a botanist. She agreed that all cereal grains cultivated in this country behaved very much in the same way. Apart from the fact that husked grains like barley were slightly less susceptible to insect attack than were naked grains such as wheat, they were very similar in their physical behaviour. Miss Hyde said she had little information on grass seeds; she thought their moisture equilibrium properties were somewhat similar to those of cereal grains, but they would probably behave differently in regard to temperature uptake.

Mr J. R. Moffatt (Rothamsted Experimental Station) said that the part played by oxygen in relation to the growth of bacteria and insects had been referred to. He asked whether there were any means by which carbon dioxide could be injected into silos in sufficiently high concentrations to reduce the oxygen content. If so, how often would an injection be needed to keep the CO^2 content high enough to prevent the growth of these undesirable organisms. Miss Hyde replied that in her laboratory's tests on airtight storage, to which she had referred briefly in the lecture, no noticeable effect had been recorded. Further experiments with which they had been connected on a practical scale had also indicated that adding carbon dioxide during storage did not prevent the anaerobic fermentation that took place during airtight storage, an aspect to which Mr Culpin would be referring in his paper.

PRACTICAL APPLICATION OF AIR-TIGHT HIGH MOISTURE GRAIN STORAGE

by

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A Paper presented at the Annual Conference of the Institution in London on 22 April 1965

Summary

An account is given of recent progress in air-tight storage of high-moisture grain for stock feeding on British farms. Types of containers and equipment used for filling and emptying are briefly described and discussed.

Emphasis is laid on the advantage of a reasonably clean grain sample of moderate moisture content, e.g. 18-21% Dirty samples and surface wetness can cause emptying troubles and should be avoided as far as possible. Silos should be filled as quickly and completely as practicable.

Processing of grain of moderate moisture content is easy, and 'shelf life' during the normal winter feeding season raises no problems. Few feeding trials have been completed, but present indications are that cattle find the grain appetising and do well on it. Further work is needed on in-silo losses in various storage conditions, especially at higher moisture contents and when grain has to be fed throughout the summer.

Advantages of air-tight high-moisture storage include ability to start harvest early and to work a long day with the combine. The general conclusion is drawn that air-tight high-moisture storage shows every sign of being able to compete successfully with other methods for preserving grain which it is known will be required for stock feeding.

1. INTRODUCTION

Commercial exploitation of the technique of air-tight storage of high-moisture grain in Britain is a very recent development. Progress in the last three years has been rapid, but there are still many gaps in knowledge concerning details of requirements for efficient preservation and utilization. The information presented in this paper is derived mainly from investigations begun in 1962 on the Ministry of Agriculture's Experimental Husbandry Farms, and from observations carried out on commercial farms by N.A.A.S. Mechanization Advisers.

Temperature measurements, gas analyses and analyses of the grain stored in silos at the Experimental Husbandry Farms have given results in accord with the early fundamental work carried out at the Pest Infestation Laboratory. At moisture contents in the region of 18-25% m.c., temperature typically does not rise much above 80°F when filling is rapid, but a maximum of about 90°F may be reached if filling extends over a fortnight or so. Oxygen content within the silo falls to a trace within about 3 days, and though it fluctuates a little when large quantities of grain are withdrawn, it quickly returns to less than 1% when the silo is re-sealed. When the silo is almost empty, oxygen content creeps up to about 3%. Carbon dioxide content rises to 60-85% in the early stages of fermentation, and then as fermentation dies down and some air enters during unloading, it gradually falls to about 12% by the time the silo is empty. Provided such results are achieved, continuous uncontrolled leaks being avoided, the barley is normally free from ordinary moulds, but a few grains are coated with a white mycelium. It is bright, free-flowing, attractive to livestock, and a satisfactory feed for all types of cattle and also poultry and pigs. Faults in construction or mismanagement can, however, lead to grain being spoiled or partially spoiled by mould, and most of these troubles are associated with inadequacy of the unloading methods or carelessness on the part of the operator. A surprisingly wide range of equipment can be effectively used in conditions of moderate grain moisture content and low temperature.

2. AIR-TIGHT CONTAINERS FOR HIGH-MOISTURE GRAIN STORAGE

The main requirements of a container for air-tight grain storage are easy filling; effective sealing; ability to deal with the chemical changes which may take place, notably the formation during the early stages of appreciable quantities of carbon dioxide by anaerobic fermentation; avoidance of excessive gaseous exchange between the gases inside the silo and the air outside, especially during the difficult periods during harvest and in the following summer, when temperature is high and the silo contains a large amount of gas and a relatively small amount of grain; and ability to remove all grain without letting in more air than the amount needed to replace the grain withdrawn.

Types of container which have been used include the following:

2.1. A type of silo first developed in U.S.A. constructed of panels of steel, with a thin coating of glass fused to both sides, and bolted together with a mastic sealer, in the form of a simple roofed cylinder. A deep layer of dense concrete forms the base. Pressure relief valves fitted in the roof operate at just under +2 and —2 inches water gauge, A large-capacity (typically 600 ft³) plastic 'breather bag' is fitted inside the roof, with its outlet

**Chief Farm Machinery Adviser, National Agricultural Advisory Service, Ministry of Agriculture, Fisheries and Food.*

passing through the silo roof and communicating with the atmosphere outside. The breather bag allows for considerable variations in atmospheric temperature and pressure, without causing gas to be pushed out through the relief valve when the silo warms up, or air to be drawn into the silo when it cools at night. It is fairly certain that the use of a breather bag can and normally does effectively reduce gas exchange between the inside of the silo and the atmosphere. This feature appears to be of insignificant importance during the winter months in the British climate, but could be well worth its comparatively small cost in the more difficult conditions which prevail when nearly empty silos are used during the period from May to September.

2.2. A type of silo similar in general construction to that described above has no breather bag and uses relief valves which operate at a slightly higher positive pressure (e.g. +4 and —2 in. W.G.). This type of silo is available from different manufacturers in the following forms:

vitreous-enamel-coated steel panels with fibreglass roof,
vitreous-enamel-coated steel panels throughout,
galvanized steel panels throughout.

This general type of silo is the most widely used at present. Some recently-developed models can easily be adapted for silage-making if desired. It is not yet possible to say whether the extra cost of vitreous enamel coating rather than galvanizing is justified by less maintenance or a longer life; but there is at present no indication that a good galvanizing treatment is inadequate. Silos with walls as well as roof made of fibreglass are being tried in some countries.

Results of using silos with only low-pressure relief valves are very similar, for grain of moderate moisture content kept only for the normal winter feeding period, to those obtained with silos incorporating a breather bag. More information is needed on relative performance with high-moisture grain kept until the summer months.

2.3. A type of silo which is welded on site employs a flat steel bottom and has a conical roof of steep pitch. The pressure relief valves operate at +55 and —5 in. W.G. Provided that the structural strength of the silo is adequate, operation of relief valves at increased pressure has the effect of reducing gas exchange, but at the pressures stated above the effect on gaseous exchange is intermediate between that of the two main types already described.

2.4. A method of nullifying the effects of gas exchange employed in U.S.A. but not at present commercially applied in Britain is the use of a subsidiary container, connected to the main silo. A pipe leading from the top of the main silo is connected to the bottom of the subsidiary container, which in turn has an unsealed outlet at the top. When gas in the silo expands, some from the top passes into the auxiliary cylinder. When temperature falls, the gas is sucked in from the bottom of the smaller cylinder, where the proportion of carbon dioxide is likely to be highest. Such devices have not been widely applied because to be effective the smaller silo needs to have a capacity not less than about one sixth of that of the silo.

2.5 Containers made of various types of plastic materials have been used for storing grain of moderate moisture content. The thinnest gauges of polythene are unsuitable due to high permeability to oxygen; but polythene of 500 gauge (.005 in.) or over can be effective if properly sealed. Plastic fertilizer bags of 800 gauge clear polythene can be satisfactory provided that sealing is below the small pin-holes which may be present 3-6 in. from the top. Disadvantages of storage in polythene are liability to accidental puncturing; the necessity to protect from rodents, and the difficulty of removing some grain from a large container without spoiling that which remains. Grain of up to about 21% m.c. usually keeps well in plastic containers where the seal is effective. Very moist grain often shows some moulding, especially where condensation occurs just below the polythene, and experiments at Hillsborough showed a loss of dry matter of over 5% in the grain stored in plastic at 22.5% m.c., as well as that stored at 33.8% m.c. Such a result cannot be regarded as satisfactory, and since plastic containers are unreliable and need frequent renewal, their initial cheapness is less advantageous than it seems at first sight. The chief use of plastic containers at present is therefore provision of emergency short-term storage at the lowest possible capital cost.

2.6. There are attractive new possibilities in the use of elastic materials such as butyl rubber. It may well be that with such materials the use of pressure relief valves can be completely dispensed with, excess carbon dioxide formed in the early stages being allowed to escape by occasional removal of the filler seal. A container of conical shape, with sealed-in ports for filling and emptying, is envisaged.

2.7. While such containers cannot be described as air-tight, it is necessary to mention the use of concrete or other unsealed tower silos. The silo walls are treated on the inside with various types of sealing materials, including bituminous or plastic paints. The silo is filled with barley of a very high moisture content (generally 30% or over) and sealed until use by means of a heavy-gauge polythene sheet or by other methods such as putting on a layer of silage. Experience to date suggests that the condensation which takes place beneath polythene can lead to some spoiling, and that other methods than simply covering with polythene are desirable. About six inches of dry chaff beneath the polythene seems a promising solution of this difficulty, which only becomes serious if there is a long delay between filling and beginning to feed. The grain is used by removal of layers from the top, preferably by means of a mechanical top unloader at a rate of a least 2-3 in. per day. This system of storage can usually only be attractive where mechanical feeding is practised, so that the grain is eaten very soon after removal from the silo. There is little difficulty in feeding before serious deterioration occurs during the winter months; but the higher the temperature, the more difficult it becomes to feed the grain before serious heating and moulding takes place. This method should still be regarded as experimental. It could become of importance at some time in the future, if large-scale production makes concrete stave silos appreciably cheaper. It has been found that barley can be successfully combined at moisture contents up to 40% and very early harvesting can help to control wild oats. However, on balance, moisture contents nearer 30% seem preferable for this system of storage. Investigations are in progress to determine (i) the effects of early cutting on yields, and (ii) effects on in-silo losses of the type of fermentation which occurs in very high-moisture crops. In-silo losses are almost certain to be higher than where grain is stored at a lower moisture content. If they are even as high as 5%, this could be a serious disadvantage of the system.

3. FILLING METHODS

For the shorter silos, filling causes few problems. The normal method is to use an inclined auger. A trolley-mounted machine with a high working rate, delivering to the central filling port, is ideal. Minor difficulties which may arise in practice when simple small augers are used are some difficulty in fixing the auger in position, and sometimes a slow rate of work. Occasionally, where the height is too great for use of a single auger, a combination of two conveyors may be employed. A few farmers use endless chain and flight elevators with good results.

For tall silos one solution is a bucket elevator, but this is usually too expensive. Normal equipment at present is a pneumatic silo filler. Some of these do a considerable amount of damage to the grain, with the result that unloading difficulties are accentuated. With most methods of filling and emptying it is worthwhile, during filling, to withdraw some grain daily, to help to avoid any tendency to bridging. One of the advantages of high-moisture grain storage is absence of any processing at harvest, but if the grain contains an excessive amount of trash, a pre-cleaning may be worthwhile. Some farmers who already have a drier, in order to avoid subsequent unloading difficulties, are prepared to process the grain before storage, even to the extent of carrying out cleaning and partial drying of a crop that comes off the combine at a moisture content above about 24% m.c.

Complete filling of the silo is desirable, and a steep conical-shaped roof facilitates this. Some settling may take place after filling with damp grain, and topping up is possible but not essential.

4. EMPTYING METHODS

Emptying silos completely, without letting in an unnecessarily large amount of air during the operation, is a desirable aim, and is essential with a plant where very moist grain has to be fed during the summer months. The problem is comparatively simple if the grain is of only a moderate moisture content (e.g. up to 21%) and all is fed by early spring. On the other hand, it is asking for trouble to ensile very wet grain in a silo fitted with only the most primitive unloading devices, especially if the grain is to be used over a very long period. Settling of soft grains in a tall tower results in appreciable compaction of grain at the bottom if moisture content is over about 24% and this can cause bridging troubles when emptying, even if no moulding or other undesirable deterioration occurs. The main methods of emptying which should be distinguished include:

4.1. Sealed sweep-arm auger and horizontal auger

The best known equipment employs a horizontal auger which runs in a trench to the centre of the silo. The trench is covered by a steel plate. The stationary auger is fed from a well at the end of the trench, in the centre of the silo. Only the fixed auger is used until for any reason grain will no longer flow into the sump. Before filling, the sweep-arm auger, which is connected by gearing to the fixed auger, is covered by a shield to protect it from the weight of grain above it. Before the sweep-arm can be brought into use by its remote-control rod, the cover must be pulled out of the silo. The sweep-arm moves round the silo simply by friction and its own rotation. It leaves only a very thin layer of grain on the flat silo floor. Even with this sweep-arm equipment, which normally works well, very high moisture contents, dirty samples or severe damage can cause temporary troubles due to bridging.

With a more recently introduced type of sweep-arm auger, which operates in a similar way, the fixed auger does not work in a trench, and the sweep arm is assisted in moving over the fixed auger by means of an inclined plate.

Another newly introduced type of sweep auger is fully independent of the horizontal fixed auger, and works on top of the grain. It consists simply of a motor and auger which are suspended from the silo roof so that the auger moves round the silo and draws grain to the centre. This overcomes the funnelling that may occur when grain at the centre of a silo flows freely to the auger, but the rest of the grain is just sufficiently caked to form an almost vertical wall.

4.2 Sealed auger working in one of three slotted tubes

The 'Trident' discharge arrangement consists of three slotted tubes set in the bottom of the silo at a suitable angle, so that if grain flows into the slots, only a little is left in the silo. This arrangement can work well with grain of normal moisture content. Vibration helps to encourage grain to flow through the slots, but bridging above the tubes can occur if excessive amounts of air are allowed to enter the silo so that the grain cakes. With a sealed auger and low-pressure relief valves, air enters the silo to replace the grain removed by passing through the inlet valve, rather than through the grain in the auger. This applies to bottom-unloading sealed augers in any type of silo, i.e. with or without a breather bag or auxiliary sweep-arm equipment.

4.3. Unsealed auger or flexible conveyor

Many silos have been emptied successfully by removing the cover plate, inserting an auger or flexible conveyor, removing the conveyor and re-sealing. This method does, however, result in more gas exchange than is necessary, and can lead to mould and caking troubles with very moist grain when the weather is warm. It is to be expected that the use of unsealed conveyors will eventually be abandoned.

5. AIMS AT HARVEST

Though it has been found practicable to store grain of very high moisture content in air-tight silos, the difficulties may be considerable if much of the grain exceeds about 25% moisture content. Experience to date indicates that the aim at harvest should be to store grain at 18-21% m.c., and it is only in exceptional circumstances that very wet grain (e.g. over 30% m.c.) should be ensiled. This means that the grain should be ripe, but that after this there are few conditions in which harvesting need be stopped provided that the combine is able to work without difficulty. It is essential, for trouble-free withdrawal of grain, to aim at a clean sample. Though barley is the crop normally stored, there is no technical difficulty in dealing with wheat or other cereals. The quicker the silo is filled, the better. Results at Gleadthorpe Experimental Husbandry Farm in 1963 showed that when filling of a silo with grain of 21% m.c. was spread over 16 days, more heating occurred than when another silo was quickly filled with wetter grain (26% m.c.). Even so, the amount of moulding was negligible, and an extended filling period need not be ruled out if a good quantity of grain is put in at the first filling, and care is taken to keep the silo sealed at all times when it is not being filled. With such care, it seems practicable on some farms to put the wetter grain into a sealed silo and to dry only that which needs very little drying. The damp grain must, of course, be loaded into the silo as soon as possible after combining, since it is very undesirable to allow spontaneous heating to develop.

Use of an air-tight high-moisture store enables a farmer to begin harvest earlier and to work a longer day. This increases the seasonal capacity of a given size of combine harvester, and so can reduce harvesting costs. It is, nevertheless, inadvisable to combine when grain is wet on the outside, since this can lead to unnecessary trouble in withdrawing grain from the silo, quite apart from the tendency to increase field losses.

High-moisture storage helps to avoid the necessity for leaving crops standing long after they are ripe in order to reduce moisture content at harvest. There is evidence that avoidance of a late harvest can result in an increased yield of grain. Experiments are now in progress on the Experimental Husbandry Farms to assess the effects on yield of harvesting at various stages of ripeness.

6. PROCESSING AND STORAGE OUTSIDE THE SILO

The 'shelf-life' of high-moisture grain after removal from the silo depends on temperature, moisture content, and the treatment which the grain receives. In mid-winter there is no difficulty in keeping whole grain of 20% moisture content for a month. On the other hand, in mid-summer, grain of over 25% m.c. which has been crushed begins to deteriorate immediately, and should only be kept for a day or two. Mixing the processed grain with dry materials helps it to stay fresh a little longer.

Grain of up to about 21% m.c. can be effectively ground in a hammer mill. Hammer milling is just practicable with a $\frac{1}{8}$ in. screen up to about 24% m.c. Crushing or coarse kibbling is preferable for cattle, and works well at 18 to about 25% m.c. At moisture contents over about 30% there is some difficulty in carrying out any normal form of processing, but reasonably satisfactory results are obtained on some farms by use of an American type of 'crimper cracker', the rolls of which can be driven at different peripheral speeds if desired.

If a large quantity of moist grain is left in the silo at the end of the feeding period, it is possible to remove this and dry it if desired. It may be dried in any of the usual ways.

7. FEEDING VALUE OF HIGH-MOISTURE GRAIN

There have so far been few trials in which all aspects of conservation at high-moisture content and feeding have been assessed. A report from the Hillsborough experimental station showed the disadvantages of ensiling very moist grain (33.8% m.c.). There was a loss of dry matter in the silo of 4.2%. Grain stored in plastic containers at both 22% and 33.8% m.c. showed a dry matter loss of over 5%. The results of further work on this aspect are awaited, but it will be surprising if there are appreciable losses of feeding value in grain of moderate moisture content (e.g. up to 21% m.c.) stored in sealed silos.

Feeding trials show that the dry-matter contained in high-moisture grain has a feeding value at least equal to that of dry grain, and that the improved appetite of stock for the high-moisture grain can result in an economically higher live weight increase. A feeding trial with 7 cwt Friesian cattle at Gleadthorpe Experimental Husbandry Farm, where silage was gradually reduced to 22 lb/day and rolled barley was fed ad lib, gave the following results:

	Type of Barley		
	Dried to	*Air-tight stored*	
	15% *m.c.*	21% *m.c.*	26% *m.c.*
Mean weight of barley consumed per day (lb)	15.0	18.7	20.7
Mean weight of barley eaten. lb dry matter/day	12.8	14.7	15.3
Liveweight gain lb/head/day	2.1	2.7	2.8

Up to 20 lb of high-moisute barley can be fed daily to 15-18 month cattle. Care is needed in introducing the ad lib feeding to cattle which have previously eaten only limited quantities.

An ideal feeding arrangement is seen in those mechanized feeding installations where the high-moisture barley is withdrawn from the silo, crushed, and delivered into the mechanical feeder to which any necessary supplements are added in the desired proportions, so that the processed grain is in the trough within minutes of being withdrawn from the silo. On most farms, however, it is quite satisfactory to withdraw the grain at weekly intervals, process it, mix it with other concentrated ingredients and feed it within about a week or ten days.

8. ECONOMICS OF HIGH-MOISTURE STORAGE

The cost of providing air-tight high-moisture storage is not very different from that of providing bulk drying in a simple on-floor installation. Capital cost per ton falls with increasing size of installation.

A typical cost for a 50-ton galvanized silo erected on a medium-sized farm where additional grain storage was justified is as follows:

	£ *gross*	£ *net**
Clearing site	30	20
Construction of base	60	40
Silo erected	645	430
	735	490

Net cost per ton—just under £10

* *After deduction of grant under the Farm Improvement Scheme.*

Filling and emptying equipment on this farm, consisting of two augers (one 31 ft mobile and one 22 ft sealed), with motors, cost an additional £140.

For a silo of 150-200 tons capacity, a typical net cost is £6-£7 per ton stored for a galvanized steel silo with simple filling and unloading equipment, £8-£9 per ton for a similar silo vitreous-enamel-coated, and £10-£11 per ton for a vitreous-enamel-coated silo with breather bag and sweep-arm auger unloading.

There is, of course, no drying cost to charge against the high-moisture store. Average drying cost for an on-floor installation, where 6% moisture is removed, is usually of the order of 10/- per ton stored. It can be higher in very wet harvests and much less in dry ones.

9. DANGERS OF AIR-TIGHT STORAGE

Attention should be drawn to some dangers which must be guarded against in practice. Successful air-tight storage results in almost complete absence of oxygen in the silo right up to the time when no more grain can be removed. If, for any reason, it is necessary to enter the silo, it is essential to take precautions against suffocation.

Silo valves must be checked to ensure that they do not leak—otherwise a very large quantity of grain can be spoiled or partly spoiled. Valves should also be checked to ensure that they are capable of fulfilling their role of avoiding dangerous pressures, which can destroy the silo if allowed to develop unchecked.

It is possible, either through mismanagement or through faulty equipment, for grain to become severely attacked by moulds and by bacteria. Types of bacteria which can flourish on damp grain which is allowed to heat include one (Thermopolyspora polyspora) that may cause illnesses in workers of the kind known as 'farmer's lung'. If grain which has caked has to be shovelled from a silo, masks should be worn by those who work inside. Damp grain can also be a host for various fungi, e.g. Aspergillus flavus, which produce highly toxic products. Advice should therefore be sought before feeding large quantities of grain which has deteriorated seriously. On the other hand, no harm usually results from feeding limited amounts of slightly mouldy grain which has been attacked mainly by the most common types of mould. These dangers should neither be exaggerated nor ignored.

10. CONCLUSION

Air-tight high-moisture grain storage is a technique which shows every sign of being able to compete successfully with other storage methods. It is at present of particular interest to farmers in the North and West who normally use for feeding on their own farms most of the barley which they grow. It is also widely applicable on mainly arable farms in drier regions, where an increase in the cereal acreage and cereal yields is producing more corn than existing drying and storage facilities can accommodate. On many such farms increasing amounts of barley are required for stock feed, and an air-tight silo is one solution to the problem of providing increased storage capacity.

There is no doubt that the ability to start harvesting early, put the crop straight into store, work a long combining day, together with the absence of dust in the feed, avoidance of any loss by vermin, and improved palatability as a stock feed are real advantages. Nor is there any doubt about the fact that the health and production of livestock which are fed on high-moisture barley are very satisfactory.

REFERENCES

Storage of Undried Grain. J. Morrison, T. J. Forbes and W. O. Brown. Thirty-ninth Annual Report (1962-3) of Agric. Res. Inst. for Northern Ireland, Hillsborough, County Down.

Annual Report of Gleadthorpe Experimental Husbandry Farm 1963.

DISCUSSION

Drawing attention to Mr Culpin's reference to the difficulties with pneumatic fillers, Mr W. T. W. Cory (Carter Thermal Engineering Ltd) said he presumed that the speaker was, in fact, thinking of the direct type of blower where the grain passed through the impeller; in other words it was not strictly a pneumatic conveyor. Did not Mr Culpin feel that the real trouble lay in damage to the grain itself bearing in mind that the tip speeds of these impellers were in the region of 110 ft per second? Would not Mr Culpin also agree whilst true pneumatic conveyors did not at present have the capacity and lift required, the studies now being carried on by one or two manufacturers in this direction were useful? Mr Culpin agreed that there was not the slightest doubt that much of the trouble was caused by damage to the grain due to its being passed through the impeller. He agreed it was incorrect to call it 'pneumatic' filling. It might be worthwhile to look again into those methods which had been customarily employed with ordinary grain storage a few years previously but which had been abandoned on account of various disadvantages. These might come back into use again for this purpose, but provision of an adequate throughput with a reasonable power requirement was the main problem.

Mr R. A. Jossaume (Cleale's Ltd) asked whether it was necessary for a silo to be vertical to obtain ease of emptying. Mr Culpin said that one of the great advantages of the ordinary silo being a vertical cylinder was in facilitating filling and emptying. He agreed there was something to be said for the idea that storage silos need not be vertical and he knew that some thought had been given to this. However, he could not conceive of any easy way of extracting grain from, for example, long horizontal silos.

Mr C. J. Swan (West of Scotland Agricultural College) referred to the dangers associated with gas in silos; one would normally expect CO_2 to be the gas with the greatest concentration. In one particular case an unloading auger had jammed in the silo and ultimately it was decided that the only remedy lay in opening the door and gradually boring in. Two men were employed on this and after the silo had been left for about eight hours with the door open and the top hatch removed, the men worked for four or five hours in the silo with no discomfort or ill effects that day. The following day, however, they were both extremely exhausted and displayed symptoms of quick difficult breathing accompanied by high temperature and painful coughing. Mr Culpin regretted that he had no information he could offer on this subject although he had heard of cases where equally unexpected things had happened. He did not believe that anybody had yet been able to investigate the troubles sufficiently to establish the causes.

Mr D. R. Bomford (Bomford Bros) also recalled an instance of CO_2 generation which he said had been quite frightening. The case in question was not a grain silo but an ensilage silo which had been filled to a height of about 8 ft. After a meal break the workmen re-entered the silo in order to continue spreading. The result was two dead men and one who only just recovered. Death had been almost instantaneous and was assumed to be caused by CO_2. Mr Bomford said that this set him wondering about the dangers of the rapid generation of CO_2 in grain silos and asked whether there had been any fatalities, so far as ordinary grain storage was concerned. Mr Culpin replied that he knew of none; in the case of the silage silo to which Mr Bomford had referred something other than CO_2 might have been the cause of the trouble. Some really toxic products could be given off by silage in certain circumstances. Mr Culpin emphasised that CO_2 itself was not toxic, and suffocation resulted only from the absence of oxygen. However, it was possible in certain circumstances for poisonous gases to be produced by fermentation. Very little was known about this. He believed that this would be most unlikely to result from the kind of high moisture grain storage he had been discussing, provided that farmers followed the recommendations regarding moisture content and sealing of the silo.

Mr B. Burgess (Ben Burgess Tractor Ltd) said that some ten years previously he had been rendered unconscious by inhaling CO_2 in a grain store, but fortunately he had been safely extracted and the only ill effect was that he had been unable to walk a straight line for some time afterwards. It had been about 24 hours before he had fully recovered his equilibrium but there had been no lasting effect. Mr Burgess felt that Mr Culpin had quite unnecessarily laboured the difficulties of extracting barley from these stores. In his experience of some 30 high-moisture grain stores this season and several the previous season, there had been only one case of difficulty, in a silo with a conical base—which Mr Culpin had said he did not like—and a particularly dirty sample of barley of about 30% moisture content. For the rest there had been no trouble whatever. One farmer had even blown the dressings from his malting barley samples into the grain store. This had been extracted in due course without trouble, but then caused difficulty in the subsequent rolling and crushing processes. Mr Burgess thought that Mr Culpin had not described the most satisfactory trident box—there was another much simpler one. The trident box method of extraction was very satisfactory and was so simple that there was no need to seek any other method of extraction. Mr Culpin commented that the experience of farmers in Norfolk appeared to differ from those in some other areas. His own investigations had revealed appreciable difficulty even during this current season. He feared that there might be hundreds of farmers next year who might think high-moisture storage was simple and easy; and if there was a wet harvest they would be unable to get their grain out of the silos without a great deal of trouble. His investigations certainly indicated that problems existed and he did not believe he had over-emphasised them.

Mr E. S. Bates (BP Limited) asked what connection there was between loss of dry matter and the high moisture content of the grain. Mr Culpin replied that there was little information on this at the moment. Experimental work was being undertaken on the experimental husbandry farms.

(*continued from page* 54)

remembered that in July of this year the first intake of students to the National College of Agricultural Engineering would be graduating. This would be the fulfillment of a dream which so many members of the Institution had fought hard to nurture. The President went on to say that he was sure that all members present would want him to congratulate Dr P. C. J. Payne and his staff on the excellent news that the Secretary of State for Education had announced the designation of the Associateship of the National College of Agricultural Engineering as being comparable to a first degree.

Mr Wilder said he felt one of his most important tasks in this speech was to express gratitude to the immediate Past President, Mr W. J. Priest. He would long be remembered for the way he had taken charge during the crisis in the Institution's affairs caused by the death of the late Secretary, Ronald Slade, in 1963, but his Presidency would be remembered also for many other reasons—for his interest in every aspect of the Institution's affairs and especially his work for the Branches—for his kindly manner, friendly smile and countryman's philosophy. A wise and sympathetic intelligence had been at the head of the Institution's affairs for the past two years. The President went on to compliment the performance of the Secretary, Mr Jon Bennett, the Assistant Secretary, Miss J. P. Housley and their small staff.

After referring to the Institution's plans for future open meetings, conferences and other activities, the President closed by saying that he was appreciative of the great honour the Institution had paid to him by electing him President and added that he would do everything possible to maintain the high standards set by his predecessors.

Other speeches during the evening included the Toasts to 'The Guests' proposed by Mr T. Sherwen, MI MECH E, MSAE, MI AGR E, President-Elect of the Institution and the response by Professor A. W. Scott, CBE, BSC, PHD (GLAS), MI MECH E, Professor of Chemical Engineering, at the University of Strathclyde. The Professor commented that there appeared to him to be a certain parallel between the chemical engineering industry and the agricultural engineering industry, in both of which he was interested. The representative institutions in each case involved two distinct disciplines. In the case of the chemical industry the situation had in the past been one of mechanical engineers and chemists 'muddling along' together. At first it had been the chemist who called the tune and it was only subsequently that engineers increased their influence. The same trend was perceptible in agricultural engineering and it was important that there should be this firm engineering basis in modern agriculture. One of the main obstacles that confronted the engineering industries today was of getting the best from the schools. It was still true that the arts and sciences had a glamour that technology lacked and in this respect the agricultural engineering industry was at least as badly off as any other.

Finally, he said that the Report of the Merritt Committee—when it eventually emerged—might well have repercussions as far reaching and important for agriculture as the Robbins Report was for education in general. Whatever resulted, it was doubtful whether the Merritt Committee could expect to receive universal acclamation.

A telegram on behalf of all present at the Annual Dinner was sent to Mr W. J. Nolan, HON MI AGR E, a Past President of the Institution offering greetings and wishing him a speedy recovery from the illness which had prevented him from being present.

GRADUATE AND STUDENT MEMBERSHIP

At the Extraordinary General Meeting of the Institution held on 22 April 1965 convened to consider amendments proposed by Council to the Articles of Association of the Institution, members present at the Meeting passed amendments to Articles 23 and 24 whereby tenure of the grades of Graduate and Student Member will henceforth be limited to ten and seven years respectively except with the permission of Council. At the same Meeting, abbreviations indicating these grades were amended to GR I AGR E and SI AGR E.

Members affected by the revisions to Articles 23 and 24 are invited to submit an application for transfer in grade of membership for the consideration of the next meeting of the Membership Committee. Such applications (made on the prescribed form) should reach the Secretary I Agr E, 6 Queen Square, London W.C.1 by 1 September 1965.

The position of members affected by the revisions who do not apply before 1 September for transfer will be reviewed early in 1966 when the new requirements for Graduate and Corporate Membership (reference the article appearing in Vol. 20 No. 1, of the Journal, *The Institution's Examinations and Eligibility for Corporate Membership of the Institution*), will have been introduced.

ELECTIONS AND TRANSFERS

Approved by Council at its meeting on 1 April 1965

ELECTIONS

Associate Member	.. .. ..	Bull, D. A.	Beds
		Hargreaves, T.	Yorks
		Randall, M. J.	Beds
		Richman, J. C. H.	Suffolk
		Towner, F. R.	Berks
Associate	.. .. ..	Haller, F.	Yorks
		Jackson, G. T.	London
		Maurice, G. W.	Yorks
		Suttie, J. S. O.	Sussex
		Watson, W. N.	Yorks
	Overseas ..	Maddox, G. R. F.	Portuguese E. Africa
	Overseas ..	Wright, A. H.	Australia
Graduate	.. .. ..	Aspinall, J. S.	Beds
		Barnes, M. M.	Surrey
		Carter, A. J.	Wilts
		Fry, J. R.	Oxon
		Meek, N. W.	Glos
Student	.. .. ..	Charlton, B.	Beds
		Darcel, C. J.	Beds
		Dennis, C. W.	Surrey
		Freer, C. S.	Beds
		Riddle, M. J.	Beds

TRANSFERS

Member	.. .. ..	West, L.	Lincs
Associate Member	.. .. ..	Pugh-Lewis, J.	Notts
		Thomas, K. M.	Staffs
		Limbrey, R. F. S.	Warwicks

BRANCH HONORARY SECRETARIES

EAST ANGLIAN

J. B. MOTT, AI AGR E
County Education Offices
Stracey Road, Norwich, Norfolk

EAST MIDLANDS

R. D. S. BARBER, BSC, ND AGR E, AMI AGR E
The Farm Institute
Caythorpe Court, Nr Grantham, Lincs

NORTHERN

H. B. HUNTLEY, M I AGRE
4 Southwood Gardens
Gosforth
Newcastle-upon-Tyne 3

SCOTTISH

J. WEIR, BSC, A M I AGR E
North of Scotland Hydro-Electric Board
16 Rothesay Terrace, Edinburgh 3

SOUTH WESTERN

J. B. PATERSON, NDA, AM I AGR E
Seale-Hayne Agricultural College
Newton Abbot, Devon

WESTERN

H. CATLING, ND AGR E, AM I AGR E
Engineering Dept
Royal Agric. College, Cirencester, Glos

WEST MIDLANDS

K. M. THOMAS, GRADUATE I AGR E
41 Birches Park Road,
Codsall,
Staffs

YORKSHIRE

T. H. E. HARRISON, BSC(AGRIC), MSC(AGRIC ENG), GRADUATE I AGR E
16 Wood Lane, Ashenhurst
Huddersfield, Yorks

Index to Advertisers

Abbreviations and Symbols used in the Journal

a	year
A or amp	ampere
ac	acre
a.c.	alternating current
atm	atmosphere
b.h.p.	brake horse-power
bu	bushel
Btu	British Thermal Unit
cal	calorie
c.g.	centre of gravity
C.G.S.	centimetre gramme second
cm	centimetre
c/s	cycles per second
cwt	hundredweight
d	day
dB	decibel
D.B.	drawbar
d.c.	direct current
°C, °F, °R	degree Celsius, Fahrenheit, Rankine
deg	degree (temperature interval)
dia	diameter
doz	dozen
e.m.f.	electromotive force
ft	foot
ft^2	square foot (similarly for centimetre etc.)
ft lb	foot-pound
G.	gauge
g	gramme
gal	gallon
gr	grain
h	hour
ha	hectare
Hg	mercury (pressure)
hp	horse-power
h	hour
in.	inch
in^2	square inch
i.d.	inside diameter
kWh	kilowatt hour

l	litre
lb	pound
lm	lumen
m	metre
max.	maximum (adjective)
m.c.	moisture content
m.e.p.	mean effective pressure
mile/h	miles per hour
mill.	million
min	minute
min.	minimum (adjective)
o.d.	outside diameter
o.h.v.	overhead valve
oz	ounce
Ω	ohm
pt	pint
p.t.o.	power take-off
qt	quart
r	röntgen
r.h.	relative humidity
rev	revolutions
s	second
s.v.	side valve
S.W.G.	standard wire gauge
t	ton
V	volt
v.m.d.	volume mean diameter
W	watt
W.G.	water gauge
wt	weight
yd	yard
$>$	greater than
$\ngtr$	not greater than
$<$	less than
$\nless$	not less than
$\propto$	proportional to
$\sim$	of the order of
° ′ ″	degree, minute, second (of angles)

The above abbreviations and symbols are based mainly on B.S. 1991 (Part 1), 1954