# THE AGRICULTURAL ENGINEER

RNAL and Proceedings of the INSTITUTION of AGRICULTURAL ENGINEERS

ume 37 AUTUMN 1982 No 3 (ISSN 0308-5732)

# THE AGRICULTURAL ENGINEER

JOURNAL and Proceedings of the
INSTITUTION of AGRICULTURAL ENGINEERS

ISSN 0308–5732

**Volume 37 AUTUMN 1982 No 3**



The AGRICULTURAL ENGINEER is published quarterly by the Institution of Agricultural Engineers
West End Road, Silsoe, Bedford MK45 4DU

Tel: Silsoe 61096

ABC

*Price £3.50 per copy, annual subscription £14.00 (post free in UK)*





## Contents



***Three categories of paper appear in the Journal:—***

*a)* ***Papers submitted to the Honorary Editor and subsequently refereed.***
*b)* ***Conference papers not generally refereed but which may be if the authors so request and if the refereeing process can be completed before the Conference Report is due to be published.***
*c)* ***Mechanisation and review articles not normally appropriate for refereeing.***

*Front cover: Monitoring the thermodynamics of a deep bed grain drying experiment (photo by courtesy of SIAE)*

# Developments in continuous-flow grain driers

## M E Nellist

**Summary**

THE design and performance of grain driers using heated-air as the drying medium are discussed mainly in relation to efficiency of energy use. A hypothetical 'ideal' drier is used to demonstrate the advantage of higher temperatures in achieving greater efficiency. Because drying air temperature can no longer be regarded as an indication of maximum grain temperature, existing safe temperature recommendations have lost relevance. Work to determine safe operating conditions for different designs is in progress. Driers can be classified according to the direction of flow of air relative to grain. Cross-flow designs are most common and are mechanically simple, but are not as efficient, nor do they dry the grain as uniformly as designs based upon concurrent- and counter-flow. There is scope for the use of microprocessors in drier control.

## 1. Introduction

THIS paper is written against the background of the current position of heated-air grain driers in the UK, which, as I see it, is one of revival. For much of the seventies we enjoyed some dry harvests during which existing heated-air driers, and an increasing number of low temperature driers, were able to cope with the increasing yields, the faster harvesting rates and the greater concentration upon winter wheat. Then, when we did have a succession of wetter summers, it was realised that a small heated-air drier could be a useful addition to an overloaded low temperature system and that many heated-air driers needed replacing with larger capacity models. Another reason for such replacement is that many older driers are unable to cope with the small seeds of the increasingly important oil-seed rape crop. Finally our membership of the EEC has increased the importance of uniformity in grain quality and intensified the move towards co-operative grain drying in semi-industrial drying plants.

One factor which might have been expected to have damped renewed enthusiasm for heated-air grain driers is the increase that has taken place in fuel costs relative to prices generally (fig 1). The increase has been crippling for the grass drying industry where the evaporative loads are extremely large and the driers already very efficient. For grain drying the evaporative loads are much smaller and the fuel cost is a much smaller component of total production cost. Nevertheless the increase has been more than enough to focus the attention of farmers and manufacturers upon drier efficiency. Six years ago I gave a paper to the Institution (Nellist 1976) in which I attempted to illustrate the opportunities for improved design offered by computer simulation. I expressed the hope also that a dialogue would develop between research workers and manufacturers. I am pleased to say that such a dialogue does now exist and that the acceptance of the value of computer simulation in research, development and advisory work has been such that I no longer feel it necessary to labour the point.

*Dr M E Nellist is head of Crop Drying and Ventilation Department, National Institute of Agricultural Engineering, Silsoe, Bedford.*

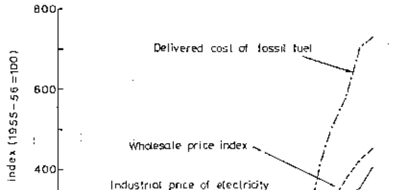



*Fig 1 Increases in the cost of fossil fuel, the industrial price of electricity and the wholesale price index (data cited in Harker & Backhurst, 1981)*

Clearly it is necessary to define at the outset what we mean by capacity and efficiency in heated-air grain driers. The most usual measure of capacity is throughput of grain expressed either as tonnes/h or, for batch driers, often as tonnes per 24 hours. This practice can sometimes lead to slight confusion because a drier does not have one throughput but a wide range depending upon several factors. The main ones are the operating temperature and the amount of moisture removed. In the UK, throughputs are usually defined in relation to a 5% (20-15%) or 6% (21-15%) moisture reduction at a single operating temperature of 150°F (65.5°C). In the days when 150°F was thought to be a suitable operating temperature for all driers, this system was fine but, as I hope to explain, different driers require different operating temperatures and, for many, 150°F is no longer relevant. Finally, it is not always made clear whether the stated throughput refers to wet or dried grain. For a 5% moisture reduction from 20 to 15% wb, every tonne of wet grain represents only 0.94 tonnes dry. On the whole manufacturers appear to use the term throughput for the wet grain entering the drier, and refer to the dried grain as output.

With the exception of some smaller driers, where a diesel unit or tractor pto drive may be used, the mechanically-driven parts of a drier are powered by electricity and the air is heated by fossil fuel. The latter constitutes over 95% of the total energy input so that the fuel consumption per tonne of grain dried can be an important measure of a drier's efficiency. I say 'can be' because once again this parameter must be related to some definite grain throughput and moisture removal. Otherwise misleading comparisons can be made. A far better measure, and the one I shall use, is the quantity of energy required to evaporate unit quantity of water. This is called the specific heat consumption or, if the electrical input is included, the specific energy consumption. In the SI system of units it is conveniently expressed in megajoules (MJ) per kologram (kg) of water evaporated. As against the latent heat of evaporation of water of 2.45 MJ/kg, specific energy consumptions of most grain driers lie in the range 3½ to 10 MJ/kg. Obviously any designer worth his salt should be aiming to produce a drier using the lower of these two figures. However, what he must not do is to complicate the design so as to add a disproportionate amount to its capital cost.

The values I quote for specific heat or energy consumption and other drier properties come from four main sources. These are drier tests, laboratory experiments, computer simulation and manufacturer's literature. Strictly speaking the values should refer to some standard ambient condition and moisture removal but the majority are not so adjusted. On the whole the variation in ambient conditions is small in relation to the total temperature rise and is unlikely seriously to affect the comparisons made. Variations in moisture removal may be more serious and where possible I have tried to indicate what the moisture removal was. Variation and bias in methods of test and computation could also be important but could seldom be identified.

## 2. The efficient use of heat

Once it has been decided to accelerate drying by heating the air, then the chances of using that heat efficiently improve with increasing air temperature. Figure 2 (Isaacs and Muhlbauer 1975) shows how the temperature to which air is heated and the degree of saturation achieved subsequently by adiabatic saturation can effect the ratio

$$\frac{\text{heat added}}{\text{mass water evaporated}}$$

ie the specific heat consumption, which might be achieved in a hypothetical 'ideal' drier. The figure is drawn for air initially at 10°C and 80% rh.

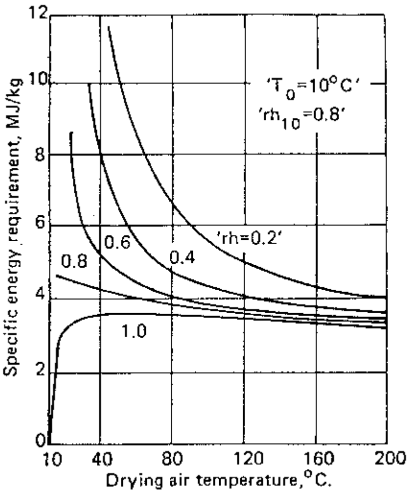



*Fig 2 The effect of degree of adiabatic saturation on the recovery of heat added to air initially at 10°C and 80% rh.*

Obviously the recovery of added heat as evaporated water will be most efficient if we can completely saturate the air and thus the lowest curve on fig 2 is that for 100% rh. Starting from zero at 10°C, the 100% rh line rises rapidly to a peak of 3½ MJ/kg at about 50°C and then gradually falls to about 3¼ MJ/kg at 200°C. For temperature rises less than 5°C, specific heat consumptions are less than the latent heat of vaporisation of water and reflect the contribution made by the enthalpy in the air prior to heating. However, such low figures are achieved only if the air becomes saturated or nearly so. If it does not, then the heat is wasted and specific heat consumptions can be several orders of magnitude higher. This 'unstable' situation for low temperature rises has serious implications for the use of supplementary heating in low temperature driers but is of concern in this paper only insofar as it reinforces my belief that low temperature drying is more difficult to manage than is popularly supposed. For high temperature driers, the importance of the diagram is that, as the drying air temperature increases, the penalty for partial saturation reduces rapidly and at 200°C, specific heat consumptions are low even for air exhausting at 20% rh (4 MJ/kg). In the UK, heated air driers are operated normally in the range 40-80°C but the latest designs are intended to operate at higher temperatures (as high as 250°C in certain cases) and so achieve the energy economy indicated by fig 2.

The other advantage which this relationship gives at high temperature is that it reduces the mass of air that has to be pumped per unit mass of grain. Figure 3 demonstrates the effect of air temperature rise on the mass of air required per unit mass of dried grain for a 20-15% wb moisture removal and at a range of typical specific heat consumptions. Clearly if we can move from temperature rises of 20 to 60°C to rises of 100 to 200°C and, at the same time, reduce specific heat consumption from the order of 8 down to 4 MJ/kg water evaporated the reduction in total flow is considerable. This not only reduces fan power but also reduces atmospheric pollution; a factor likely to become of increasing importance in the operation of drying plant.

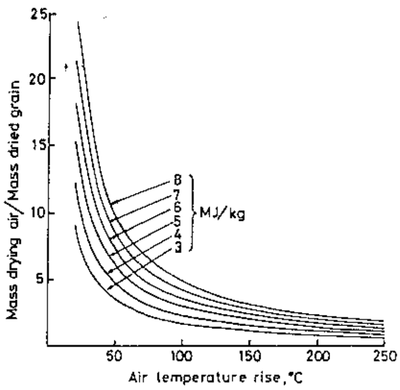



*Fig 3 Effect of air temperature rise and specific heat consumption on the mass ratio of drying air to dried grain for a 20 to 15% m c w b removal*

Thus once we are committed to the use of heated air, we need to heat as little as possible to as high a temperature as possible without causing unacceptable damage to the grain.

## 3. Drying temperature and grain quality

So far I have been talking about the temperature of the drying air. In discussing the effect of drying on grain quality, it is necessary to distinguish between the temperature of the drying air and that of the grain since they are not the same and, as we shall see, the difference between them depends very much upon the design of the drier.

So far as grain quality is concerned, it is the grain temperature history which matters.

What is meant by damage and what is an acceptable level of damage depends upon the use to which the grain is to be put. Damage to the enzyme system of barley grain which might render it useless for malting may be of no consequence to its value as stockfeed. Thus it is usual to find that recommendations for 'safe' temperatures are made either at national level or by manufacturers and tend to be classified by the four main end uses, malting, seed, milling (baking) or feeding (table 1). The problem with the existing UK recommendations (Cashmore 1942, MAFF 1944) is that being nearly 40 years old they reflect the knowledge and technology of their time and are not appropriate to modern driers. In 1942 it had to be assumed (i) that the grain temperature became that of the drying air and (ii) that it did so instantaneously. Not only do we now know that this was a gross over-simplification but we are now able to design driers in which the maximum temperature reached by the grain is many degrees below that of the drying air. Because of the importance of design I believe that in the future the individual manufacturers will have to accept responsibility for specifying 'safe' operating regimes for their driers and I hope that at the research level we can provide the data necessary for them to do this.

**Table 1 Current UK recommendations for maximum temperature of the drying air according to end use. (Cashmore, 1942, MAFF 1944)**

| | *Moisture content % wb* | *Drying air temperature °C* |
|---|---|---|
| Malting | | |
| barley and | < 24 | 49 |
| seed grain | > 24 | 43 |
| Milling wheat | < 25 | 66 |
| | > 25 | 60 |
| Grain for | | |
| stock feed | | 82—104 |

It is appropriate at this point to summarise briefly the present state of our knowledge in this area.

### 3.1 Stock feed

The least demanding use for grain is as feed for stock and, in the case of ruminants provided the grain is not physically charred, it may be both more palatable and more easily digested in the rumen, if it has been slightly toasted. In rations for non-ruminant stock, the grain may be an important source of protein and protein denaturation should be limited. Muhlbaüer and Christ (1974) found reduction in the availability of the protein lysine a useful measure of damage and suggested an upper acceptable limit of 10%. Combinations of grain temperature and time of exposure which they found to give such a reduction are plotted in fig 4 as a solid line. In comparing results from a number of workers, I found (Nellist 1978) that this line did separate experimental treatments which had damaged grain from those which had not. Thus it would seem that a temperature of 120°C can be tolerated for periods up to one hour and 100°C can be tolerated for up to three hours. What this means in practice is that damage to feeding grain is not a problem in most existing driers which are simply not capable of raising the grain to these

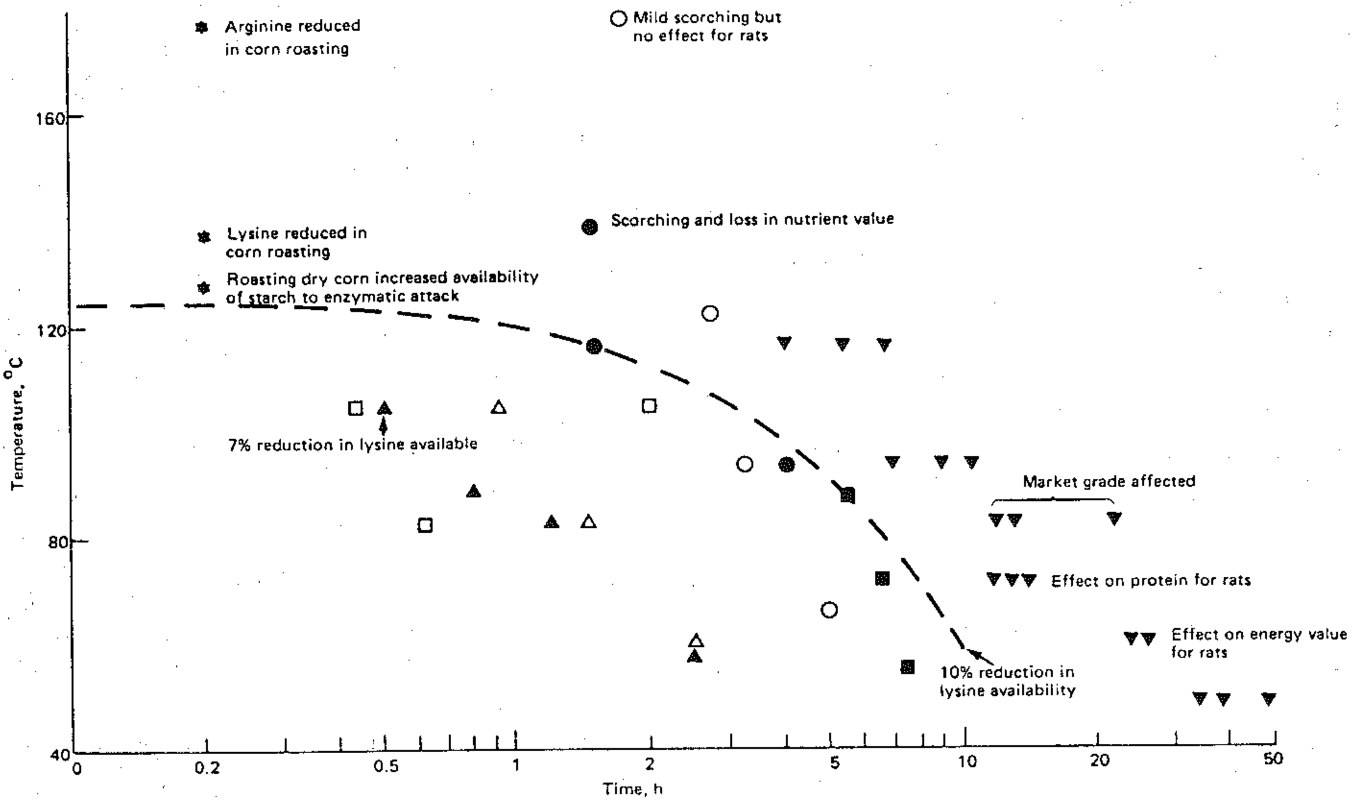



*Fig 4 Combinations of temperature and exposure time reducing lysine availability by 10% (dotted line) compared with results from eight other workers and showing that adverse treatments generally fall outside the line (Nellist, 1978)*

temperatures and for which the maximum operating temperature is limited by the difficulty of cooling hot grain.

**3.2 Seed grain and milling wheat**
Criteria for milling wheat should not be markedly different from those for seed grain since in both cases damage implies destruction of the enzyme systems and a similar level of protein denaturation. Thus the capacity of the grain to germinate has been found to be closely correlated with loaf volume (Ghaly 1974, Bailey 1972) and is the criterion of damage to milling wheat specified in the British Standard for testing agricultural grain driers (BSI 1966).

In some ways germination is an excellent criterion since this one single property reflects a number of chemical and physiological changes and is an accepted commercial criterion. However, there is a difficulty in using it as a measure of drying damage in that the amount of damage which can be accepted, say a one or two per cent depression is of the same order, or less, as the experimental error in the germination test. Another problem is that each batch of grain has a different initial germination and apparent resistance to heat damage.

At Silsoe we have been working to resolve some of these problems using an approach (Nellist 1981) to expressing the rate of loss of seed viability which was pioneered in work on seed storage by Professor E H Roberts of Reading University. This work is expected to have three applications:—

a) It will provide us with a means of detecting grain damage with a greater certainty and precision than hitherto.

b) It will enable us to describe such damage in units (rather akin to soil pH) which will be an additive and which will be independent of the initial quality of a particular grain sample. In other words if a drier is found to cause x units of damage, these might be translated into y and z losses of germination for 2 samples of differing initial viability.

c) Together with our work on the mathematical modelling and computer simulation of drier types, we should be able to calculate the safe operating regimes for a particular design. We should also be able to identify an area or areas in a drier at which temperature sensors will provide us with a guide to the maximum grain temperature. In the majority of cases, I think it will be adequate to measure the temperature of the air exhausting near to the end of the drying chamber and that settling upper limits to this temperature will be entirely compatible with its use for control of final grain moisture content.

In the interim we could perhaps conclude from NIAE tests (1956-1967) on 7 cross-flow, and one mixed-flow, driers that plenum air temperatures of 66°C (150°F) are unlikely to cause any reduction in seed viability.

## 4. A drier classification

There are many detailed differences in mechanical design between driers but the most important basis for the classification of drier types is the relative direction of flow of the grain and air. It is crucial because of its effect on the temperatures which have to be endured by the grain. The air may cross the path of the grain, it may flow along in parallel with it and it may flow along in parallel against it. Thus we have the three basic types (i) cross-flow, (ii) concurrent-flow and (iii) counter-flow.

**4.1 Cross-flow**
Cross-flow driers are the easiest to design both mechanically and with a minimum understanding of drying thermodynamics. Thus we can follow the empirical development of this type from the drying of a bulk of seed in a static deep layer, as for example, in a large tray with a perforated base. By way of revision,

*Fig 5 Development of a drying zone in a static bed*

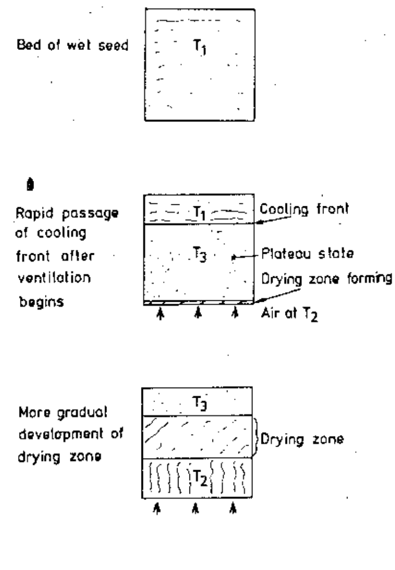


fig 5 shows the development of a drying zone in such a bed.

It will be accepted, I hope that the process obeys the laws of physics and, given that some of the necessary properties of the grain are measured, then the progress of drying in terms of changes in moisture content and temperature can be calculated. The calculations are tedious and are, therefore, carried out on a digital computer but there is nothing magical about them and I hope that I can proceed on the assumption that 'mathematical models' of grain drying are an accepted part of the drying engineer's tool kit.

Returning to fig 5 and the bed of grain dried in a batch mode. In practice, drying would be continued until the mean moisture content of the bed has reached some desired level. Unless this target moisture content is also the equilibrium moisture content of the drying air, there will be a dispersion of moisture contents about the mean depending upon the relative depths of the bed and the drying front.

The transition from a batch to a continuous-flow drier can be visualised as replacing the drying *times* for the batch by the *distance travelled* for the continuous process. Thus fig 6 shows either a series of batch driers at progressively longer drying times or the development of a complete drying zone along the length of a continuous-flow drier. In practice, of course, the excessive moisture gradients, which drying with heated air would give, are avoided by reducing the depth below that of the drying zone.

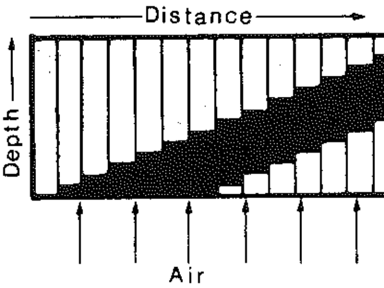



*Fig 6 The transition from batch to continuous cross-flow*

The main features of the cross-flow drier are summarised by fig 7 (left):—

a) Grain on the inlet side, q, dries first, and, by the time it leaves the drier, may have almost reached the inlet-air temperature.
b) Grain on the exhaust side, p, remains very much cooler and wetter.
c) The difference in moisture content between the inlet and exhaust sides makes mixing after drying essential.
d) The grain is shown moving horizontally but, of course, there are both vertical and inclined bed arrangements of this design.

### 4.2 Concurrent-flow

In concurrent flow, (fig 7, middle) the grain and the air travel in the same direction. Thus wet and cold incoming grain meets hot and dry air. There is a rapid conversion of air sensible heat into latent heat of vapourisation of water evaporated from the grain. This cools the air and ensures that the peak temperature reached by the grain is well below the temperature of the air at inlet.

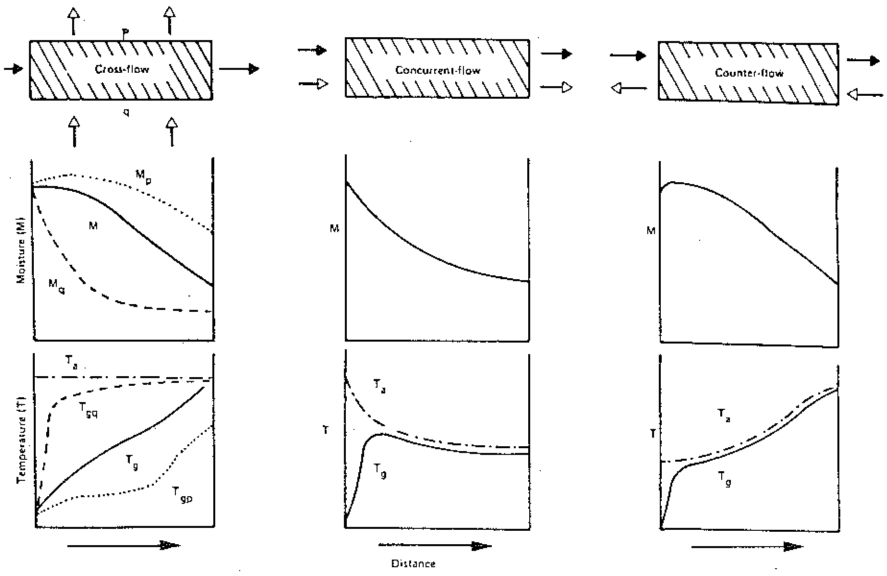



*Fig 7 Moisture and temperature changes in the three basic types of hot-air drier, cross-flow (left), concurrent-flow (middle) and counter-flow (right.) Direction of flow of crop (g) and air (a) indicated by black and white arrows respectively*

Figure 8 shows some results from a single stage laboratory concurrent-flow drier in which drying air temperatures in the range 140-260°C only resulted in maximum grain temperatures of 50-90°C. (Bakker-Arkema, *et al* 1977).

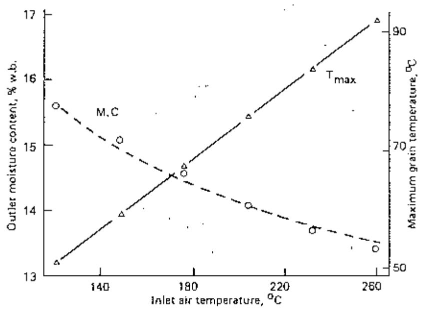



*Fig 8 Effect of drying air temperature on outlet moisture content and maximum grain temperature for a single-stage laboratory concurrent-flow drier (Bakker-Arkema, et al, 1977)*

Compared with cross-flow, this type of drying is efficient because, (i) the high temperatures minimise the quantity of drying air needed and hence the proportion of heat wasted in the exhaust air and, (ii) all the grain receives the same treatment. Thus no energy need be wasted in overdrying. Quite apart from the fact that the latent heat transfer allows higher air temperatures to be used, the uniform treatment of the grain also allows the safe temperature limits to be approached more closely.

### 4.3 Counter-flow

In counter-flow, (fig 7, right) the grain travels against the flow of the air. When this process reaches a steady state, the grain is exhausting at, or near, the hot air temperature and the air is exhausting at, or near, temperature and humidity equilibrium with the wet grain. This process is efficient but its use for grain drying is limited by the sensitivity of the grain to high temperature. It is more suitable for cooling hot dry grain.

## 5. Practical designs

### 5.1 Cross-flow

Commercial heated-air driers embody one or more combinations of the three types described above. Until recently almost all driers of UK design and manufacture used cross-flow for drying and cooling (fig 9). In some cases a small improvement in efficiency is obtained by recycling the cooling air through the drying section. Evidence from NIAE tests carried out between 1960-1966 suggests that simple cross-flow driers use between 5 and 9 MJ of heat energy per kg of water removed.

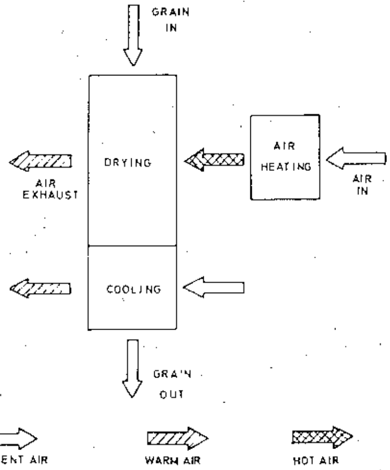



*Fig 9 Schematic representation of a simple cross-flow grain drier*

One American drier, the Hart-Carter, recycles both the cooling air and the air leaving the second half of the drying section (fig 10). The direction of flow is also reversed between the first and second halves of the drying section and this reduces the range in output moisture content. Table 2 compares the computed output moisture content and specific heat

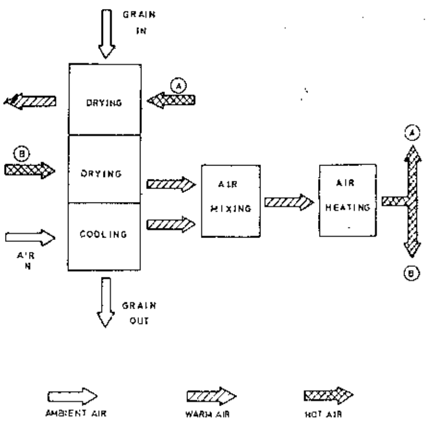



*Fig 10 Air and grain flow in cross-flow drier with recirculation of cooling and some drying air and reversed second drying stage*

consumption for conventional and improved Hart-Carter driers (Stevens and Thompson 1976). The moisture range is reduced from 7.7 to 2.8% w.b. and the specific heat consumption from 5.69 to 3.31 MJ/kg water evaporated, a 42% saving. In tests on a Ferrell-Ross cross-flow drier, Bauer *et al* (1977) obtained a reduction in specific heat energy consumption from 7.44 to 5.47 MJ/kg by using air recirculation, a 30% saving. In two recent tests (Bakker-Arkema *et al* 1981) on a Hart-Carter drier, specific energy consumptions of 4.7 and 5.4 MJ/kg were measured.

Reducing the moisture gradient in a cross-flow drier is a desirable end in itself and one way in which it can be done is to invert the grain as it descends the column. In experimental and computer simulated tests on an Ace drier, Otten *et al* (1980) found the inverter to be effective but that it slightly reduced throughput and increased specific energy consumption. A design which has become very popular in the UK in recent years is the small batch-drier in which the grain can be recirculated through an annular drying chamber by a central vertical auger. This effectively reduces the moisture gradient but presumably with some increase in specific energy consumption. It is probably worth adding that these driers are not necessarily bought on the grounds of fuel economy.

Tests in Canada (Scott 1980) and a recent survey in Scotland (Langley 1981) suggest that there may be problems with hot spots and mechanical reliability.

A recent introduction to the UK market has been a range of cross-flow batch driers in which the drying air alternates between adjacent drying beds at 15 second intervals. The resulting rest periods are claimed to allow moisture equalisation giving increased moisture loss during the ventilation cycle and less damage to the grain. So far we have no direct or indirect experience by which to judge these driers.

### 5.2 Concurrent-flow

From what has been said in section 4, concurrent-flow is clearly an attractive drying principle but in practice it is not easy to arrange for the uniform distribution of the hot air into the cold grain and there are no true concurrent-flow driers on the UK market. In the United States the M & W Gear Co, the Andersons (Anderson 1972) and Westelaken developed concurrent-flow driers which consisted basically of a concurrent-flow drying section and a counter-flow cooling section (fig 11) and for which specific energy consumptions of 3½ to 4 MJ/kg were claimed. Subsequently both Westelaken (1977) and the Andersons (Hall and Anderson 1980) moved towards multistaging. The Anderson BIRD (Batch Internal Recycling Drier) is in effect a single-stage concurrent-flow drier which achieves multistaging by recirculating a batch of grain. The advantage of doing this seems to be that higher temperatures can be used in the initial cycles than if the grain were dried in one pass. This slightly increases the efficiency whilst further reducing the possibility of grain damage.

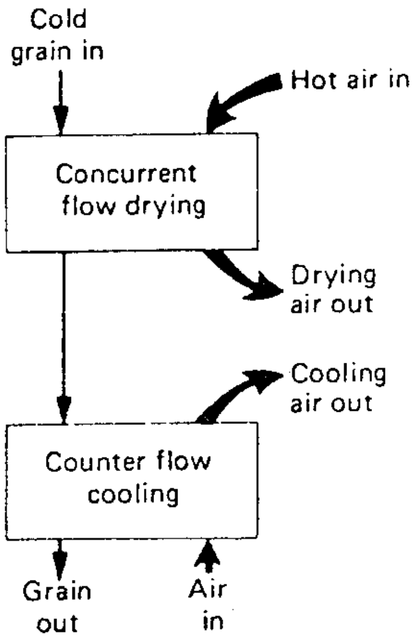



*Fig 11 Schematic representation of a single-stage concurrent-flow drier*

In 36 tests at drying air temperatures in the range 260 — 427°C, specific heat consumptions, adjusted to a base ambient temperature of 4.4°C, ranged from 3.1 to 3.7 MJ/kg and maximum grain temperatures ranged from 54.4 to 63.9°C. These results, which were for maize are very much in accord with those obtained for wheat by Bakker-Arkema *et al* (1977), by Muhlbaüer (1971) and in computer simulation studies eg Baughman *et al* (1971), Meiering (1977).

### 5.3 Mixed-flow

So concurrent-flow drying appears to be a sound principle but North American designs are not entirely suited to European conditions and none are marketed here as yet. When, or if they are, they will face competition from a common European design type which does not appear to be very popular in North America. This is the mixed-flow, alternate flow or cascade drier which achieves some of the advantages of concurrent-flow without mechanical complexity. In mixed-flow designs, grain descends by gravity through a tower in which there are many layers of horizontal ducts. The drying air is introduced to, and exhausted from, alternate layers of these ducts (fig 12) and produces a combination of concurrent- and counter-flow with some element of cross-flow.

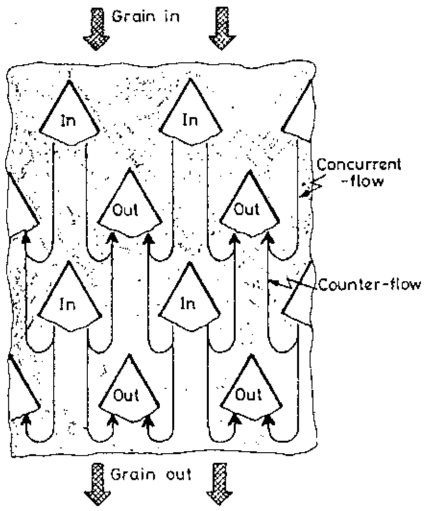



*Fig 12 Distribution of air through ducts in the mixed-flow drier*

The driers are efficient and can use of the order of 40% less air than their cross-flow counterparts. Also the air-flow paths are relatively short and allow the use of low pressure fans. This leads to a difference in electrical power requirement (fig 13) which becomes of increasing importance as the demand for new and replacement driers moves towards higher throughput. Another feature which has been given added value by the expansion in the growing of oil-seed rape is the absence of any, easily-blocked, perforated metal separating grain from air.

The French organisation CNEEMA (now CEMAGREF) have tested three mixed-flow driers, all of which are available in the UK (table 3). The Law SC109 is a straightforward mixed-flow drier and under the test conditions had a specific energy consumption of 3.97 MJ/kg water evaporated. The FAO GD170E and Law SCE112S both reheat, and recirculate through the upper part of the drying column, the partially saturated air from the lower part of the drying column and the cooling section. By this

**Table 2 Comparison of output moisture range and energy use of conventional cross-flow drier compared with the Hart-Carter modified drier (Stevens and Thompson 1976)**

| | *Conventional* | *Hart-Carter* |
|---|---|---|
| Output mc, % wb | | |
| Mean | 15.0 | 15.0 |
| Range | 10.6 — 18.4 | 13.1 — 15.9 |
| Difference | 7.7 | 2.8 |
| Specific energy consumption | | |
| Kj/kg water | 5691 | 3306 |

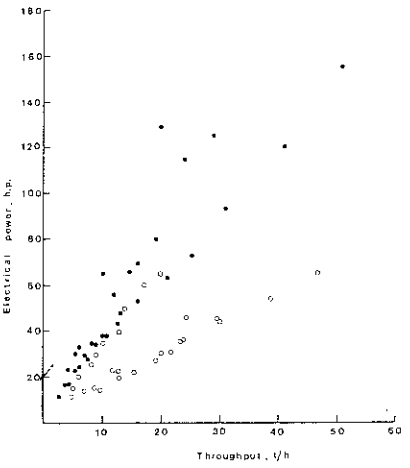



*Fig 13 Electrical power requirements of cross-flow (●) and mixed-flow (●) driers (Derived from data in 'Buyers' Guide to Grain Driers, Power Farming, November, 1981)*

means, specific energy consumptions of 3.54 and 3 MJ/kg respectively were achieved but not apparently without some difficulty in reheating the recirculating air. It is significant that in both cases the current models differ from the ones tested in the means by which they achieve reheating and recirculation. Cimbria (1980) claim that in their model SAE-9, air recirculation reduces specific heat requirements to 3.87 MJ/kg compared with the 4.80 MJ/kg of the standard model AE-8. Although these figures may not appear as good as the French driers, it should be noted that they relate to drying from 18 to 14% wb and at 71°C.

Overall it can be concluded that the performance of mixed-flow driers is not too much different from that claimed for true concurrent-flow driers so that the introduction of concurrent-flow driers into European markets may depend upon the relative capital cost. In the meantime, having seen the increasing popularity mixed-flow driers, three UK manufacturers, who previously made cross-flow driers, introduced mixed-flow models at the Royal Smithfield Show in December 1981. Although one is a Danish model to be made under licence, two of the driers are of wholly British design.

### 5.4 Counter-flow

So far as I am aware, there is only one true counter-flow drier on the UK market. This is a system which fits into a circular grain bin and discharges hot grain for slow cooling in a separate bin as in the 'dryeration' method.

An interesting experimental development in Germany has been the addition of a counter-flow drying stage to a concurrent-flow drier (Muhlbaüer 1979). Although much lower air temperatures have to be used in the counter-flow stage, it is claimed that the combination is as efficient and gives higher rates of moisture removal than concurrent-flow drying alone.

## 6. Other aspects

There are several other aspects of grain drier design and performance which this paper has not covered, and cannot cover in detail, but which should be mentioned. One is fuel; years ago many grain driers were coal-fired but the great majority are now oil-fired with an increasing proportion using either natural or bottled gas. I expect to see moves towards using coal again and also, of course, towards the use of straw, as is happening already in France. Both of these fuels may pose problems of furnace control and of grain pollution. Grain dust is another form of pollution and I expect to see more emphasis on its control together with control of fan noise.

For control of the drier itself, I think a move towards the use of microprocessors is inevitable. How far we shall go in sophistication will depend upon cost but there is great scope. At its lowest level the microprocessor can take care of many of the manual operations necessary to the initial setting of the drier, although some of the devices, notably burners, will have to be improved.

Microprocessors have good memories and could remember such values as drying air temperatures or bed temperatures required for different crop types. But the real advantage will come in the more sophisticated variation of throughput, and possibly air temperature, to control the output moisture content. It can be shown that for a given drier operating at a constant inlet temperature there is a close relationship between output moisture content and exhaust air temperature and hence most driers adjust grain throughput to maintain this temperature constant. The throughput is adjusted by altering the grain discharge rate. Even though only done in a crude 'on-off' fashion this type of control can be remarkably effective. However, it cannot anticipate large variations in initial moisture content and given that suitable moisture sensors can be developed, then a signal derived from the input grain could be used to modify the exhaust temperature feedback loop. The computer simulation of the drier can be used here first of all to study the likely behaviour of a proposed control system and then be incorporated into the control system itself albeit in simplified form. Microprocessor based control devices for driers already exist but at about £5000 apiece are too expensive for the farm market. Much cheaper solutions must surely be possible.

My final point concerns cooling. Computer simulation confirms test data which indicate that in many cases the size of the cooling section is inadequate to cool the grain to safe storage moisture contents. The best cooling section is one which allows the grain a long residence time with low air flow. Then the grain is not only cooled but also some useful and very efficient drying occurs. Taking this to its logical end, it is probable that the best and cheapest way to cool is in the storage silo as in the American technique of 'dryeration'. Certainly I feel that if a cooling section is included in a drier, then it must work. Otherwise, it can be a source of serious trouble in store.

## 7. Conclusions

**7.1** Unless they are related to a definite moisture removal and operating conditions of the drier, conventional measures of drier throughput and of fuel use can be misleading. Specific energy consumption is a useful measure of drier efficiency.

**7.2** Effective use of the heat added to the air depends upon maximising the temperature rise and the subsequent degree of saturation. The effect of degree of saturation decreases with temperature rise. For a given specific heat consumption, the mass of air required per unit mass of grain dried is inversely proportional to temperature rise.

**7.3** United Kingdom recommendations for safe drying temperatures are relevant no longer. New safe temperatures will be specific to individual designs. Manufacturers must bear at least some of the responsibility for determining safe operating conditions for their driers. A new approach to the loss of seed viability should allow drying damage (i) to be predicted by computer, (ii) to be expressed in units independent of the initial quality of the grain and, (iii) to be determined experimentally with a precision not possible by the conventional germination test.

**7.4** Driers may be classified on the direction of movement of the air relative to that of the grain. Traditional UK driers are of cross-flow type. Although cheap and simple, their energy consumption is high and the grain is not dried uniformly. Both concurrent- and counter-flow types dry the grain uniformly but the former is more suitable for heat sensitive material such as grain. Mixed-flow driers are a combination of both types, which are more efficient and can use higher air temperatures than cross-flow driers.

**7.5** We may expect to see developments in the application of microprocessors

**Table 3 Performance of three mixed-flow driers (2 with air recirculation) under test at CNEEMA (1975, 1978, 1979)**

| | | | | |
|---|---|---|---|---|
| Manufacturer | | Law | FAO | Law |
| Model | | SCI109 | GD170E | SCE112S |
| Date of test report | | Oct 1975 | Dec 1978 | Nov 1979 |
| Moisture content, % wb | Initial | 38.4 | 39.3 | 32.9 |
| | Final | 16.2 | 19.1 | 17.4 |
| Air temperatures, °C | 1st stage | 120—147 | 143—157 | 132—170 |
| | 2nd stage | NA | 91—99 | 95—107 |
| Specific energy consumption, | MJ/kg | 3.97 | 3.54 | 3.43 |

to drier control and in the use of fuels such as coal and straw.

## 8. References


**Anderson R J** (1972). Commercial concurrent-flow heating — counter-flow cooling grain drier — Anderson model. Paper No 72-846, Am Soc agric Engrs, St Joseph, Michigan.

**Bailey P H** (1972). High temperature drying of cereal grains. MSc thesis, University of Newcastle-upon-Tyne (Unpublished).

**Bakker-Arkema F W, Ahmadnia-Sokhansanj A, Green R** (1977). High temperature wheat drying. Paper No 77-3527, Am Soc agric Engrs, St Joseph, Michigan.

**Bakker-Arkema F W, Rodriguez J C, Brook R C, Hall G E** (1981). Grain quality and energy efficiency of commercial grain driers. Paper No 81-3019, Am Soc agric Engrs, St Joseph, Michigan.

**Baker W W, Fosdick S, Walker L P, Bakker-Arkema F W** (1977). Testing of a commercial sized conventional cross-flow and modified cross-flow grain drier. Paper No 77-3014, Am Soc agric Engrs, St Joseph, Michigan.

**Baughman G R, Barre H J, Hamdy M Y** (1971). Experimental study and simulation of concurrent-flow driers. Paper No 71-319, Am Soc agric Engrs, St Joseph, Michigan.

**British Standards Institution** (1966). Methods of test for agricultural grain driers. British Standard 3986:1966. BSI, London.

**Cashmore W H** (1942). Temperature control of farm grain driers. *J Min agric,* 49 (3), 144-145.

Cimbria Unigrain Ltd (1980). Moisture and heat balances for standard drier Type AE-8 and air-recirculating drier Type SAE-9. Data sheets 96 and 97. Cimbria Unigrain Ltd, Thisted.

Centre National D'Etudes et d'Experimentation de Machinisme Agricole (1975). Official test of the Law, Type SCI109 Continuous-flow grain drier. Report No 1856 CNEEMA, Antony.

Centre National D'Etudes et d'Experimentation de Machisme Agricole (1978). Official test on continuous grain drier, Make FAO, Type GD170E. Report No 2588 CNEEMA, Antony.

Centre National d'Etudes et d'Experimentation de Machinisme Agricole (1979). Official tests of Law Type SCE 112S, continuous grain drier with heat economiser. Report No 2688, CNEEMA, Antony.

**Ghaly T F, Edwards R A, Ratcliffe J S** (1974). Heat sensitivities of air-drying wheat. A proposed technique to predict properties of exist product of a spouted bed drier, *J agric Engng Res, 19* (3), 289-298.

**Hall G E, Anderson R J** (1980). Batch international recycling drier. Paper No 80-3515, Am Soc agric Engrs, St Joseph, Michigan.

**Harker J H, Backhurst J R** (1981). *Fuel and energy.* Academic Press, London.

**Isaacs G W, Muhlbaüer W** (1975). Possibilities and limits of energy saving in maize grain drying. *Landtechnik,* 30(9) 397-401.

**Langley A** (1981). Survey of mobile recirculating batch driers. Tech Note No 283 E/C, East of Scotland College of Agriculture, Edinburgh.

**Metering A G, Hoefkes H J** (1977). Use of computer simulation in the determination of performance and energy requirement of grain driers. *Grundl Landtech,* 27 (1), 1-8.

Ministry of Agriculture, Fisheries and Food (1944). Hot air temperatures for grain driers. *J Min Agric,* 51 (5), 231.

**Muhlbaüer W** (1971). Drying of grain maize by concurrent-flow method at high temperatures. *Grundl Landtech,* 21 (1), 1-5.

**Muhlbaüer W, Christ W** (1974). Permissible exposure times of maize for animal feeding when drying at different kernel temperatures. *Grundl Landtech,* 24 (5), 161-164 (Translation No 392, natn Inst agric Engng, Silsoe).

**Muhlbaüer W, Kuppinger H, Isaacs W** (1979). Development of a concurrent-flow/counter-flow continuous drier for grain and maize. *Grundl Landtech,* 29 (4), 131-140.

**Nellist M E** (1976). Drying hay and grain. *Agric Engr,* 31 (3), 55-60.

**Nellist M E** (1978). Safe temperatures for drying grain. Report No 29. natn Inst agric Engng, Silsoe.

**Nellist M E** (1981). Predicting the viability of seeds dried with heated air. *Seed Sci & Technol,* 9, 439-455.

NIAE (1956). Report on tests of 'Kaybee' grain drier Type WCT-100. Test Report No 138, natn Inst agric Engng, Silsoe.

NIAE (1960). Report on test of Penney and Porter Series II 5/21 grain drier. Test Report No 254, natn Inst agric Engng, Silsoe.

NIAE (1962 [a]). Report on test of Gascoigne 3/40 grain drier. Test Report No 313, natn Inst agric Engng, Silsoe.

NIAE (1962 [b]). Report on test of Gascoigne 3/70 grain drier. Test Report No 314, natn Inst agric Engng, Silsoe.

NIAE (1962 [c]). Report on test of Airwoods Prototype Model II continuous grain drier. Test Report No 343, natn Inst agric Engng, Silsoe.

NIAE (1963). Report on test of Airwoods "40" (Gascoigne 4/40) grain drier. Test Report No 360, natn Inst agric Engng, Silsoe.

NIAE (1964). Report on test of Allmet 50 cwt grain drier, D400/63 Series. Test Report No 414, natn Inst agric Engng, Silsoe.

NIAE (1967). Report on test of SF 'Fluid Bed' grain drier Type 12 TBH:d2. Test Report No 570, natn Inst agric Engng, Silsoe.

**Otten L, Brown R, Anderson K** (1980). A study of a commercial cross-flow grain drier, *Can Agric Engng,* 22 (2), 163-170.

**Scott D W** (1980). Performance of grain driers under actual field conditions. Paper No 80-103, Am Soc agric Engrs, St Joseph, Michigan.

**Stevens G R, Thompson T L** (1976). Improving cross-flow grain drier design using simulation, Trans Am Soc agric Engrs, 19 (4), 778-781.

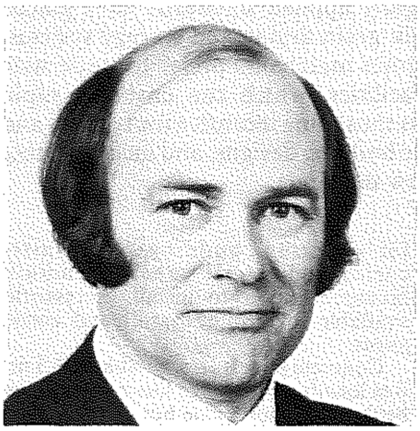
**Westelaken C M** (1977). Concurrent-flow commercial grain driers — The Westelaken Models. Paper No 77-3016, Am Soc agric Engrs, St Joseph, Michigan.

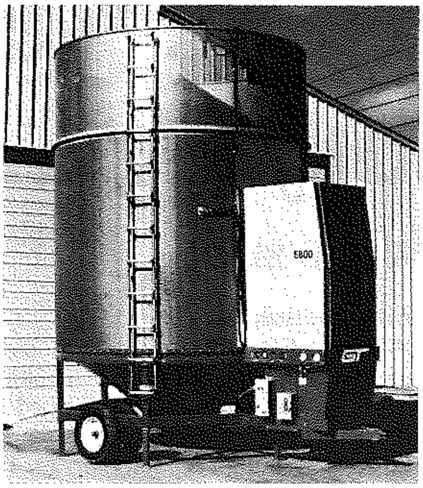
# Mobile grain driers

## A D Wilcher

**Summary**

The mobile grain drier has made a significant impact upon the traditional fixed installation for a variety of reasons, amongst which its flexibility of operation, portability and relatively low cost must figure prominently.






*Opico GT5880 continuous flow grain drier*

### The mobile drier

A DEFINITION of mobile is "portable or readily relocatable" and mobile driers are independent of building structure. A range of mobile grain driers are available and these may be categorised into three broad groups.

*a) Mobile recirculating batch driers.* Radial airflow from a central cylindrical plenum chamber through the grain is provided by a pto operated axial flow fan. Heat is typically provided by an LPG vapourising ring burner. Grain is continually recirculated during drying and may complete twelve passages through the drying chamber during a typical two hour drying cycle. Grain leaving the recirculating auger falls two feet into the drying chamber and loses moisture to the air as it drops.

There is a reliable relationship between moisture content and grain temperature for any specific crop being dried at a specified grain temperature and this relationship can reliably be used to signal the end of the drying period.

Recommended air temperatures for drying generally agree with nationally accepted standards and there appears to be little justification for attempting to use higher temperatures.

*b) Mobile continuous flow driers.* Outwardly of similar appearance to the batch drier, these have greater drying capacity and are better suited to service as part of an established handling and storage system rather than a truly mobile system, even though they require no specific civil engineering works. The thickness of the grain wall is much less than in the batch drier but plenum air temperature control is again automatic.

*c) Mobile concurrent flow grain driers.* Considerable time and research have been devoted to the principle of co-flow drying, the results of which are embodied in these designs. Of higher capital cost than the others here described, the mobile co-flow drier competes with existing fixed drying systems in the USA.

### Costs

Capital cost comparisons with other driers are difficult to make but table 1 is based on manufacturers' list price for 1982, declared out in tonne/hour when reducing moisture from 20% to 15%.

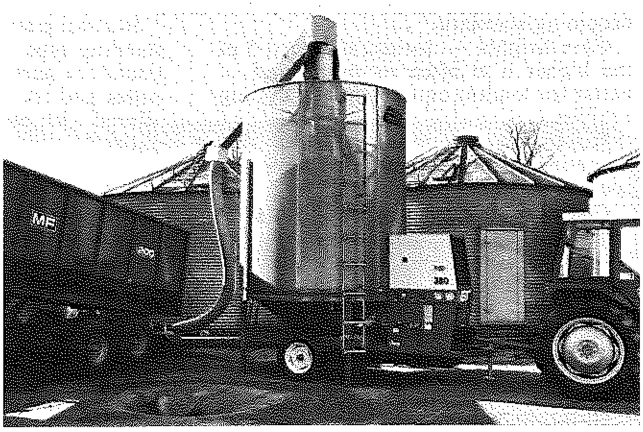
The type of fuel used has less effect on running cost than the effect of standard of management. The liquid petroleum gas vapourising ring burner allows direct heating and a low cost installation and compares very favourably with the more expensive diesel fired unit which has to have a high/low flame system.

*Mr A D Wilcher is service manager Opico UK Ltd.*

### The future

The first microwave drier has been tested in Iowa. Using a combination of vacuum, microwaves and heat exchangers, the manufacturers' envisage extremely rapid rates of drying using small amount of energy.

The recent rediscovery of ionic exchange and the effect of energy transference may have an impact on grain drying. One might even think of solar energy amplification applied to field drying situations.




*Opico GT380 recirculating batch grain drier*

**Table 1 Capital output comparisons**

| Make | Type | *Output t/h* | *Fuel list price £* | *Capital cost per output £/t/h* |
|---|---|---|---|---|
| Mobile driers | | | | |
| Dry-Mor | CB | 2.1 | 10,200 | 4850 |
| Opico-GT280 | RB | 3—3.5 | 10,000 | 2800—3300 |
| Opico-GT380 | RB | 4—4.5 | 11,500 | 2600—2900 |
| Opico-GT580 | RB | 6—6.5 | 15,000 | 2300—2500 |
| Opico-GT5880 | CF | 10 | 16,500 | 1650 |
| Static installations | | | | |
| Alvan Blanch | CF | 2.5 | 6,930 | 2770 |
| Dry-Mor | CF | 4.8 | 16,000 | 3330 |
| Dry-Mor | CF | 7.75 | 23,000 | 3000 |
| Alvan Blanch | CF | 10 | 14,840 | 1480 |
| Dry-Mor | CF | 11.4 | 31,500 | 2760 |
| Dry-Mor | CF | 16.0 | 20.770 | 1300 |

*CB - Continuous batch*
*RB - Recirculating batch*
*CF - Continuous flow*
*Note: The above prices do not include elevators, installation etc*

# Some developments in floor drying and storage of grain

**K W E Bindloss**

## Introduction

IMPROVED cereal yields and more rigidly applied standards have placed unacceptable strain on many existing bulk grain drying and storage systems. Farm labour resources are limited and grain merchants prefer to trade with those producers having bulk loading facilities, which can ensure a rapid turnround of high capacity lorries. There is thus some incentive for farmers and designers collectively to produce new basic building designs, and incorporating new equipment, which will meet these new demands.

## Buildings

CONVERTED barns and disused stock buildings offer short term cover but suffer from the disadvantages of poor accessibility, unsafe walls, limited headroom and poor ventilation. Modern structures offer a choice of purpose-built steel framed, concrete and timber buildings conforming to BS 5502. Spans are available to suit storage requirements. An economical standard span is 20 m which suits lateral air duct lengths.

Bay lengths — usual 4.5 m but 6 m becoming standard.

Eave heights — normal standard 5 m the higher 6 m often recommended — better for loading equipment and tipping vehicles.

Roof pitches — usually 15° or 12°. Sometimes a steeper pitch required for specialised filling equipment.

Cladding — normally 'big 6' in grey asbestos. Darker colours especially for vertical sheeting now common to blend with countryside. Roof lights not recommended in order to discourage birds. Ventilation is essential to prevent condensation based on 0.4 $m^2$ per 1 $m^3/s$, position gable ends.

Doors — usually in ends, recommended minimum size 4.5 m x 4.5 m. Choice of sliding or roller types.

Fanhouse — integral, exterior to building to avoid recirculation. Size minimum 4 m x 4 m, or to suit larger fan.

Walling — now often an integral part of building supported from stanchions; often neater and saves cost.

Package buildings — many manufacturers now offer standard selections. Includes grain walling, doors, fanhouse. Advantage, only one supplier to deal with, often saving in costs.

## Grain walling

Wide range available — choice of steel, concrete or timber. Generally 2.5 m or 3m depths recommended for drying but higher available. Now also available for surcharged storage. Normally forms integral part of building but also available with self supporting columns, ie for existing buildings galvanised corrugated steel panels generally favoured, easier to install. Accessories available to flashings, seals and corner joints.

Concrete panels — available in 4.5 m x 6 m lengths, advantage less corrosive and better insulation value but not so easy to erect.

Timber panels — often used in localised areas, sometimes preferred. Easy to install and easily adapted but prone to damage by determined rodents.

Internal grain barriers — platform free standing type in both steel and timber. Useful for partitioning in sections within stores and for blocking doorways. Also offered with perforated bases for drying floors.

## Main air ducts and laterals

a) *Main air ducts* — wide choice available, both steel and timber. More care now taken by manufacturers in design to withstand grain thrusts and comply with airflow requirements of 10 $m^3/s$. Consideration made for personnel access, minimum heights usually 2 m. Most now available in modular sections, basic width can be extended in height to suit grain depths and airflow requirements. Range of accessories available such as catwalks, handrails minimum 1 m high, access doors and ladders required to meet safety requirements. Offered with choice of surface or level floor outlets, one or both sides of duct at 3 ft, 1 m or 3 ft 9 in centres depending on manufacturer.

b) *Lateral air ducts and surface-type laterals* — still quite popular and widely used. Cheaper initially to install but present difficulties in unloading store. Consequent damage by machinery and replacement costs are high.

One development that has overcome unloading problems is the "Sweep" lateral. This blows grain to integral conveyor setset below floor level and sealed in main air duct. Operated by sealed grain inlet slides adjacent to lateral air control doors. Air from main fan "sweeps" grain to conveyor through directional louvres in side of tapered lateral up to a maximum of 10 m.

Grain is then conveyed to an elevator at one end of main air duct for loading out. Laterals can be used also for existing systems providing some means of conveying system can be installed below floor level either side of main air duct. Outputs of up to 30 t/h are claimed but costs are high and resemble those of in bin installations without any advantages. More generally seen used for emptying square silos.

A very recent development in surface lateral is a retractable type. Will fit most air ducts. Extends to maximum length of 10 m and can be retracted by special winch provided to 2 m even when store is full, thus leaving remaining floor area free for unloading. Considered however that some basic design features still require attention before perfected. Has potential especially in dual purpose building required for stock.

## Level floor laterals

Noted general move towards this type in recent years. An obvious advantage is that they provide an unobstructed floor for unloading equipment and vehicles and this has led to an increased popularity.

Most recent developments are constructed of galvanised pressed steel interlocking slats with louvred vents on upper side, and designed to withstand a wheel load up to 5 tonne. Usually supported in new installations on concrete piers constructed over sub floor. Depth varies according to length of lateral run and related airflow requirements for tonnage stored. Building work costly to construct. Available in widths of 0.30 m, 0.38 m and 0.46 m to provide greater airflow requirements in longer runs. Also available in timber slats.

Other forms are available, more often on existing concrete floors, are constructed in timber panel units with expanded metal strips inserted into grooves in hardwood slats supported on timber bearers set at intervals to provide passage of air. Depth of bearers can be increased to provide for greater airflow requirements. Ideal for conversions. End panel only in each section is removable for cleaning out. Could provide rodent problem over the years. Usually installed by manufacturers.

## Fans and controls

A much greater selection is now offered, and the designer has a choice from pto driven, diesel engine driven, centrifugal and axial.

Choice of fan is influenced by power

*Mr K W E Bindloss is grain storage manager, P A Turney Ltd.*

supply available, tonnage stored, airflow requirements and controllability.

The trend is to use coupled smaller fans. Because of larger stores and greater volumes of air required, two or three fans can be set in parallel.

An interesting development is the humidity control unit.

### Mechanical handling and cleaning

Systems currently used:— loading store, trolley operated augers, throwers, high output elevators, chain and flight elevators and pneumatic conveyors. Disadvantages — moved often require supervision, very dusty, trailer waiting time. Unloading store depends on lateral system. Similar equipment with collector arrangement, pneumatic suction units — limited output.

More often favoured with level floor laterals are fork lift trucks with big capacity buckets.

# Engineering developments in co-operative central grain drying, storage and marketing

P A Webb

## Introduction

The concept of a co-operative central storage system is not new. Such systems have been successful in France for many years, but only in the last decade have they become significant in the UK. These systems utilise many of the techniques found in many of the larger, more modern on-farm installations but there have been a number of specific engineering developments.

The existing generation of co-operative central stores is largely based on individual machines and components supplied by a number of manufacturers and assembled as a package by a designer. There are very few examples of custom designed and manufactured systems.

## UK cereal production and consumption

Table 1 shows the land area producing wheat and barley in UK, and average yields. Total yield of wheat and barley in 1981 was 19M tonnes and is expected to reach 26M tonnes by 1985. Self sufficiency in feed grains has been achieved, but only 60% of millers' wheat requirements are met by home produced grain, reflecting the millers' need for North American hard wheats, which cannot be grown in UK. Some 1.13M tonnes of cereals were exported from UK in 1978/79 and the volume of exports is expected to reach 6.5M tonnes by 1986.

## A central storage and export facility

As a development along these lines, a new co-operative central store with shiploading facilities was constructed for the 1981 harvest at Shoreham Harbour in Sussex, developed by a group of Sussex farmers requiring additional drying and storage, but who were already part of a UK marketing federal, and would, therefore, be able to maximise the export potential. To illustrate the developments and engineering aspects for this new concept, we can examine more closely this plant.

The basic specification was drawn up requiring some 12,000 tonnes of storage together with intake drying, cleaning and handling facilities capable of receiving cereals at rates of up to 1000 tonnes/day, although capable of 2000 tonnes/day, when receiving grain during shiploading operations. Due to the limited available area on the proposed wharf-side site, it was decided to operate the store in conjunction with an existing co-operative store some twenty-five miles away to the west, which would handle all specialist cereals from the area, the new store dealing solely with feed samples.

The design comprises a 200 tonnes/h drive-over reception pit and five 7.31 m diameter x 400 tonnes grain reception hoppers used for both wet grain intake prior to drying, and for serving the shiploading facility. The machinery house contains the cleaning, weighing and handling facilities and there are four 14.6 m diameter by 2750 tonnes capacity storage silos.

Apart from the intake to the hoppers, handling in the plant is rated at 80 t/h and the shiploading system is designed to operate at 300 t/h, to enable vessens of up to 4000 tonnes to be loaded within the day.

## Civil engineering

Owing to the site ground conditions it was decided, after a thorough site investigation and sinking of test bores, to pile all foundations using 254 mm x 73 kg U/C driven piles. Those supporting the storage silos to be driven in a ring in order to support a reinforced concrete ring beam, each pile being designed to take a load of 65 tonnes. During driving operations the piles were test loaded and found to achieve their designed strength at a depth of 12 m. As there was an existing concrete slab over the area of the site, it was decided to take advantage of this where possible and the slab was broken out in a ring to receive the storage silo piles, the base design requiring a granular fill to the remaining area of the base after formation of the ring beam.

Owing to the loads involved, it was calculated that some sinkage would occur within the ring beam and a sliding joint was therefore incorporated. Trenches for the low-volume aeration system and discharge conveyors were cast in the centre slab, and the equipment laid out in such a way that should sinkage occur, it would not be affected.

Piling was not necessary for the hopper bulk machinery house steelwork foundations, although these were heavily reinforced. Due to the high water table, elevator pit depths in the machinery house were kept to a minimum and a 6mm thick waterproof steel lining inserted, after sheet piling.

In practice, we found that the centre slabs to the storage silos have settled between 20 and 35 mm within the ring beam, although this has not presented any difficulties.

## Handling equipment

For reasons of economy it was decided from the outset that off-farm grain reception and processing would not be carried out simultaneously with shiploading and the intake elevator was, therefore, used for both functions, and rated at 300 t/h, whilst the reception pit has a two-speed drive to enable a capacity of 200 t/h on wet grain intake, and 300 t/h for shiploading direct from road

**Table 1 Area and yields of wheat and barley in UK**

| | Wheat | | Barley | |
|---|---|---|---|---|
| *Year* | *Area* $10^3$ *ha* | *Yield* *t/ha* | *Area* $10^3$ *ha* | *Yield* *t/ha* |
| 1976 | 1231 | 4.46† | 2181 | 3.75† |
| 1977 | 1076 | 4.65* | 2400 | 3.85* |
| 1978 | 1253 | 5.27 | 2353 | 4.23 |
| 1979 | 1372 | 5.20 | 2347 | 4.03 |
| 1980 | 1441 | 5.65 | 2338 | 4.34 |

† *Average 1969–1979*

* *Average 1974–1978*

*Mr P A Webb is director of T A White Installations Ltd.*

vehicles. All wet grain intake hoppers are fitted with low-volume aeration, each hopper being fitted with three 200 mm diameter x 3.65 m long perforated ducts to be connected by the trouser-leg junction to a 2.25 kW centrifugal fan having an output of 1 $m^3/s$ at 127 mm wg. This facility enables reasonable batches of one sample of material to be amassed and held prior to drying, to facilitate economical runs to be made and obviate frequent changes in machinery settings.

In the machinery house a 70 t/h pre-cleaner/dresser is installed on the first floor and being fitted with a scalping reel and twin head/tail aspiration, can effectively deal with any standard of intake sample prior to drying and storage. It is also capable of cleaning to intervention standards in one pass. To enable the cleaner to be set efficiently and to maintain a steady throughput, it is fed by a 20 tonnes buffer hopper, with high/low switches controlling the intake hopper discharge conveyor. This control system was desirable as the conveyor is rated at 300 t/h to be used when ship loading, and the incorporation of the cleaner buffer hopper allows it to operate with a minimum number of start/stop actions.

The drier capacity at 46 t/h, 5% extraction at 120°C is perhaps somewhat higher than would perhaps be normally installed in a plant of this size, but it was felt that in drawing grain from a considerable area at high daily intake rates, the extra capital cost would be justified in difficult seasons. The machine is in fact of twin-column design reducing the overall height, and enabling drying operations to continue on one column should any mechanical problems arise with the other. A liquid insecticide spray head is fitted in the drier discharge conveyor, fed by a diaphragm type pump and mixing tank in the machinery house. A capacitance probe switch in the conveyor determines the presence of material and cuts out the insecticide flow by means of a solenoid valve on the spray head, should no grain be present for any reason.

Discharge from the storage silos is effected using a horizontal chain conveyor installed in a trench cast in the base slab, the conveyors being fitted with a 20° bend section at the drive and to enable these to feed into the hopper discharge conveyor, which is mounted at ground level. This system was incorporated to obviate the need for raising the storage silo base level unnecessarily high, and each chain conveyor has the capacity of 100 t/h. The conveyor is fed by a central silo outlet, together with two further intermediate outlets, each controlled by rack and pinion slides outside the silo. After reaching the angle of repose during gravity discharge, the remaining grain is emptied using a permanently installed screw-type sweep-arm discharger, the drive gear of which is mounted in a sump at the end of the conveyor trench. A double bevel gearbox allows transmission to both the recovery screw and the progression drive, incorporating a ratchet advance mechanism, with torque limiting clutch to prevent overload and wheel slip should the advance speed be in excess of the grain recovery rate. This conveying system allows material from the storage silos to be recirculated through the plant for recleaning or drying and also for shiploading where grain is held in the storage silos in addition to the intake hoppers.

## Shiploader

During the plant design stages, several systems for loading vessels in the 2000 to 4000 tonne range were examined, and due to the fact that the ships are accommodated in a locked basin with no rise or fall due to tide, a slewing, luffing and telescoping spout solution was adopted, of a design similar to that used in the Europort Grain Terminal at Rotterdam. The spout itself is supported on a 3 m x 4 m x 17.2 m high structural steel tower, and a control cabin mounted on the floor below the spout slewing ring, allows the operator to control all functions of the spout, whilst maintaining a view of the vessels' holds at all times. As the vessel size is relatively small, and the loading time short, the ship can be ranged along the quayside to enable the spout to feed the different hatch positions.

During shiploading operations, grain brought by road vehicle for direct loading can be weighed over the 50 tonne electronic weighbridge, although it has been found in practice, that a loading rate of 200 t/h is the maximum possible during this operation, due to the limitations of time for processing vehicles through the system.

For direct loading from either the intake hoppers or storage silos, greater loading rates can be achieved, material being routed through a hopper scale mounted on the first floor of the machinery house. This unit has a hopper dump capacity of 1500 kg and a 25 tonne capacity feed hopper fitted with high/low level switches to control the silo discharge machinery allows the operator to set nominal silo discharge capacities without the need to adjust these constantly to achieve optimum scale throughput. The feed to the shiploading spout from the scale is via the main elevator and a 1000 mm wide belt conveyor connecting the machinery house with the loading tower.

## Plant control systems

Whilst for certain operations such as shiploading and wet grain intake during harvest, it is necessary to increase the labour force, the plant itself is operated by one man from a central control panel. All functions in the panel are through a Symax SCP 20 1K microprocessor having a capability for 256 input/output signals, individual circuits being protected by miniature circuit breakers. As all operating sequences fall into a set number of chosen routes, these are predetermined and selected by interlocking push buttons, the chosen route being proved through the microprocessor, which evaluates signals from bin level switches, conveyor flow switches and the electro-pneumatically operated slides so that the operation of one push button brings on line all required machines for the selected route. Time delays built into the processor enable sequence starting for the machines, and the route interlocked so that in the event of a machine failure or flow blockage, all machines downstream from that point are shut down, leaving upstream equipment running to clear any material in flight. All belt and bucket elevators are fitted with bottom shaft rotation detectors and a double threshold time delay built into the processor to provide a warning of underspeed on the first threshold, any further reduction of speed then providing a sequenced shutdown. The control panel itself is fitted with a rear engraved mimic diagram showing all available routes, together with lamps for the respective motors and flow switches.

In addition to the interlocking sequence actuators, individual hand/off/auto switches are fitted for each machine, to allow these to be operated independently of a microprocessor in the case of failures, or for running machines to clear blockages.

The storage silos each have eight pendant type temperature sensors supported on bonded hawsers mounted from the silo roof structure, and a monitoring unit mounted on the control panel provides constant temperature scanning with printout and high level alarm should the contents of the silo increase in temperature to a predetermined value. The storage silo ventilation fans are controlled by the temperature monitoring system, enabling ventilation to commence at a high temperature reading, the fans stopping again once the predetermined low temperature level has been achieved.

## Operating experience

Some problems were experienced with the low volume ventilation ductwork in the intake hoppers, due to the high loadings during discharge at rates of above 100 t/h, and additional strengthening has been necessary to overcome this.

Whilst the shiploading equipment was rated originally at 300 t/h wheat, in practice it has been found that rates in excess of this can be achieved, and in fact 320 t/h is now the normal outloading rate.

However, it has become apparent that to achieve high daily outloading rates a continuous operation is necessary and even very small delays, for example during ranging of the vessel along the quayside, can effect the throughput considerably.

Initial estimates of throughput at an export silo have been considerably exceeded during the first six months of operation, largely due to an increasing awareness amongst shippers of the efficiency and turnround achieved when loading vessels, and whilst it was envisaged originally that all grain for shipment not stored in the silo would be brought in by road vehicle during the loading operations it has been found in practice that considerable economies in haulage rates can be achieved by bringing in the required tonnage over a period of several days and storing this prior to outloading. In addition, the limitations in tonnage when loading direct from road vehicles make it necessary to ensure that adequate storage exists to accommodate this build up prior to loading. In practice it is impossible for the silo staff to plan ahead the vessel arrival time and often two or three vessels will arrive within the space of a day or so. In this instance it is imperative that sufficient grain is available for loading direct from storage, in order not to incur high demurrage costs.

All equipment installed in the plant has performed very satisfactorily, in many instances exceeding the design ratings. Expected export throughput in the first year of operation is approximately 120,000 tonnes, roughly double that originally thought possible and the plant is now attracting considerable commercial tonnage from grain merchants and shippers in the south of England, so providing the viability of the original £1,000,000 investment made.

# Storage and conditioning malting barley

**O T Griffin**

**Summary**

BARLEY is a low grade coarse grain predominantly used for livestock feeding. This is due to the difficulty of removing the husk from the grain and the gummy nature of the endosperm which produces an unpalatable form of porridge and not very palatable biscuits. Historically only limited quantities of barley were used for human consumption although there is a steady trade in the UK of about 7000 tonnes of pearl barley used in soups. Whereas other cereals can be easily milled and then extracted, the only effective process for getting the starch out of barley is by dissolution — the starch has to be converted into a sugary solution that can be separated from the husk and most of the protein and endosperm cellular structure by sieving over screens. Historically the husk is retained intact to act as a filter aid and separation occurs in a batch vessel called a mash or lauter tun. Approximately 70% of the original barley dry matter can be recovered in this manner in a solution with approximately 90% carbohydrate, 5% protein, 5% ash. This recovery compares well with the dry separation of wheat in flour making, and as with milling the residue is used as cattle food when it is called brewers grains or draff. The extract from the barley is made into beer, malt whisky, vinegar, confectionery, or malted milk drinks, but on a world wide basis almost all of the 15 million tonnes of processed barley are made into beer. In the UK 2 million tonnes are processed with 1 million tonnes going to beer, between half and 1 million tonnes into whisky and the balance of approximately a quarter million tonnes are exported for extraction elsewhere.

Clearly there is a sufficiently large market to warrant your Institution's attention and I welcome the opportunity to give you this paper on the process stage after harvesting and drying and preceding the malting process which itself precedes milling and extraction.

Let me trace backwards and forwards a little in order to give you more understanding of what we are trying to achieve.

BARLEY is harvested in dry climates at about 11% moisture and requires only limited cleaning before malting. In Britain we have to dry the grain as quickly as possible after harvest to the self same 11% at which the grain is stable; moreover this drying needs to be carried out as near to natural hot weather climate conditions as possible — a gently dry air breeze at about 100° F and in practise no more than 120° F, ie 50° C.

The process of dissolving the barley is preceded by malting. In this the barley is wetted and aerated at 15°C for six days during which the grain sprouts. This simple biological action initiates a complex biochemical dissolution of the endosperm gums so that when the barley is redried it is no longer hard but easily crushed between the nails and can be cracked open with a simple set of roller mills. The grist after further wetting at 65°C produces the mash from which the carbohydrate can be eluted by drainage, dilution and spraying. The key to the malting process is the initiation of germination.

Each grain is a separate factory in its own right so that the process time is set by the slowest grain in the bulk. Apart from the onset of germination the process time is affected by the grain size and the variety of barley which combined work out to the quantity of gum that each kernel is to dissolve. The theoretical minimum time after germination has occurred varies from 3-6 days and the British varieties selected for malting have a dissolution time of 3-4 days and the total process time of 6-7 days depending on how rapidly the slowest grain can be made to germinate. You can see that the time spent in initiating germination with grain that has been properly processed still represents almost half of the normal malting time. In former times the initiation of germination could take up to one week.

Those of you with knowledge of the seed trade will realise that this is much faster than is expected for seed grain — whereas the soil germination is slower than the seed test the malting industrial route is faster than the laboratory test — the 4 ml germinative energy.

Any endeavour to increase the speed of germination will have profound effects on the barley quality and its value — not only by reducing the time of processing and hence enabling faster throughput, but as significantly reducing the process dry matter loss which runs at between 1 and 2% per day.

We can define the conditioning of barley as that processing after drying which minimises the time delay before the onset of germination in the malting process.

There are some delays in the malting process itself. These delays are the time involved preparing the barley for setting, the subjugation of dust, and the flotation of "lights" and the time for water to penetrate to the germ. Then there is the delay after wetting while the oxygen in the air gets to the germ (the concentration of oxygen in water even on the drained barley is usually only adequate to support the respiration of the microflora, nothing being available to the germ until the water is fully absorbed). And then there are the inadequacies of ventilation equipment causing variable oxygen tensions throughout the steeping vessel, as well as dessication of exposed grain. On top of this is the physical effect of temperature and water uptake and the physiological time delay before the germination "trigger" occurs.

In practice the germination rate is maximised between 20 and 25°C with some delay outwith this range, death occurring above 30°C, and inactivity below 8°C. However, the most rapid initiation is only effective if the "trigger time" is lowered: the delay which occurs given the right environment. Because of the "trigger time" the temperature of the initial germination is usually restricted to 16°C as the "trigger" is more limiting than the temperature of the environment. What ideally can be a 12 hour germination initiation is usually extended to 36 hours by lower than optimal temperatures and longer than necessary wetting periods. And frequently this delay does not manifest itself in extension of the total malting time as the endosperm modification is more effective at lower temperatures even though the rate is lower. This would seem to be because of higher enzyme development at lower temperature initiations. The only known means of affecting the enzyme development is the supplementation of the plant's own gibberilic acid (ga): a practice that is frowned on by purists. It is theoretically possible to eliminate all germination and modify the endosperm after careful rolling of the wet barley and application of the ga — a technique that often inadvertently occurred in older plants with a history of poor quality malt. Some evidence suggests that b indolyl acetic acid applied with ga or the use of Kinetin and low levels of abscissic acid can have similar stimulatory effects: but the evidence is confusing. Quite likely the reaction applies when the conditioning is incomplete and consequently is difficult to study in mature barley.

Whilst this may seem a little heavy for

*Mr O T Griffin is employed by Tore Mill Ltd.*

you as engineers, I hope that you will see the difficult biochemical territory in which premalting processing exists: and it is an area that has very little systematic study; but rather in regionalisation of malting barley production in the driest parts of the country with the smallest need for post harvest conditioning. However these districts have their drawbacks, not least a qualitative tendency to small grains and high protein content, and commercially that the areas are remote and consequently expensive from the major areas of malt usage.

The simplest expedient for creating a high germinative rate is to simulate warm weather conditions after drying. In the laboratory, barley held between 10 and 12% moisture for 3 days at 50°C will usually germinate between 95 and 100% on the maltsters 3 day test. If moisture is lower than 10% the conditioning rate is prolonged and may be totally interrupted whilst above 12% a temperature of 50°C will cause death. As continuous driers usually have difficulty in drying below 12% moisture the room for rapid conditioning is limited, whilst in batch driers complete mixing is important before conditioning to make sure of an even moisture. In practice barley dried from air temperature of 50°C has a temperature of between 30/35°C after drying so that conditioning is prolonged for about 2 weeks in practice further losses of heat in conditioning make it more usual to hold the grain for about 4 weeks at 25°C before cooling is commenced to avoid insect infestation.

I expect this will come as a shock to those of you used to the need for a cooling section at the end of the drier. Certainly if the grain is over 12% it does need cooling and this itself goes a long way to explain why maltsters are usually anxious to carry out these operations themselves.

Notwithstanding this thermal treatment some varieties are still "dormant" — a condition of slow germination. As the germination rate continues to improve with time it is clearly not due to inadequate germination metaboloites but due to interference with the germination trigger. TRIUMPH is a very high quality spring barley that shows this problem and is also one much related to location being more prevalent in northern England than Scotland. A similar problem is now found in Scotland with winter barleys. At this stage the causes of this problem are unclear. They are not cured by prolonged heating or by a vernalisation period with the wet grain; I have been told privately that Kinetin can overcome the problem whilst it is not unusual to "run such barley around" in which the mechanical knocking tends to break the dormancy.

I personally believe these problems are related to the inability of the oxygen to get to the germ. If this is so, increasing the oxygen tension might be beneficial but I know that other people consider the problem to be one of ripeness.

At present to avoid these problems, and their prolongation in unsuitable farm stores Scottish maltsters take in almost their entire annual requirements of barley at harvest time, dry the lot and store it warm as I have previously described.

The second part of this paper is devoted to storage. In England it is customary to segregate the harvest into numerous grades defined by nitrogen content, variety and grain appearance. These grades are made up into widely differing priced products (with little absolute analytical difference). To achieve segregation, English maltsters store barley in blocks of steel and concrete silos — usually taking in their premium grain at harvest time. As such silos are expensive for storage alone, the poor quality of the barleys making up the lower priced products are only accepted at maltings when space exists in the silos after some of the higher quality barley has been used. In England approximately one third of the maltsters requirements are taken in at harvest time and the remainder later in the year.

So quite clearly different attitudes to maltsters storage exist depending on the need for conditioning, the variety of grades, and the speed of acceptance from the farms. The absolute quantity of storage has to be adequate to take the complete harvest and as the use of existing storage is cheaper than erecting new, new storage is largely dependent of the growth in size of the grain harvest. The UK cereal harvest is growing to a small extent by acreage, but predominantly by increased yield. An extra 35,000 tonnes/year storage would seem to be required from yield improvement. In Scotland the shift into cereal production has been more dramatic; the historic cereal crop of oats was largely used on the farm for feed for which the most primitive storage now that cash sale barley growing has developed into a major enterprise large central granaries have been built.

# Engineering developments for the drying, storage and handling of cereals

## Questions following Paper 1 — (M E Nellist — Developments in continuous flow grain driers)

**Professor T A Oxley (University of Aston)**

Q. I was very interested in your description of drying grain using the "dryeration" process. In my book published in 1944 (with Mr Burrell) I advocated, following some experimental work, that grain should be dried in several stages. What progress is being made towards multi-stage grain drying as opposed to the single-stage-plus-cooling of the dryeration process?

A. *The larger concurrent flow driers have several tempering sections in which the grain is rested for 30 minutes before passing to the next drying stage. These driers are particularly useful for paddy and rice drying where it is very important to avoid over stressing the endosperm. This overstressing can occur with steep moisture gradient within the kernel, and can lead to cracking and breakage. A recently imported drier has intermittent drying/resting cycles of 15 to 20 seconds each which, I believe, may be of too short a duration for maximum effectiveness.*

**Mr P H Bailey (Scottish Institute of Agricultural Engineering**

Q. It has been suggested that dryeration would lead to larger driers which would necessarily be more expensive in capital cost. I believe that the drier designed to incorporate a dryeration system need be no larger than driers currently available if bins were provided for intermediate storage between the successive drying stages.

**Mr W S Shattock (Consultant)**

Q. Would the speaker please let us know exactly what figure he has in mind when he describes the rate of airflow as 'low'.

A. *1/30th to 1/50th of the normal airlow rate associated with the system.*

**Mr G T Sampson (Alvan Blanch Development Co Ltd)**

Q. Whilst the benefit of rest periods between successive stages of drying — each with smaller moisture reductions must be recognised, would the speaker not agree that such a method leads to overcomplication of the drier design. The fuel efficiency of a good design of cross flow drier is just as good as that of a mixed flow.

A. *The mixed flow drier is more efficient than the cross flow.*

**Mr O T Griffin (Tore Mill Ltd)**

Q. What effect does the relative humidity of the ambient air have in dryeration and is operation of the method restricted to relative humidities of less than 75%?

A. *With air at 40 to 50° C, this is not a problem.*

**Mr J H W Wilder (John Wilder (Engineering) Ltd)**

Q. I would like to make two points rather than ask a direct question. 1. A saving in rate of fuel usage is not nearly as cost effective as accurate control of the drying process itself and I would equate a ½% saving in drier cost with a 47% saving saving in fuel cost. 2. Accurate control is available now without the benefit of microprocessors — for example on the Robomatic series which my company produces.

A. *This may be so, but new developments are coming along and farmers are under increasing moral pressure to reduce fuel consumption.*

## Questions following Paper 2, (A D Wilcher — Mobile grain driers)

**Mr P H Bailey (Scottish Institute of Agricultural Engineering)**

Q. Mobile driers are easy to sell and set up but are not problems likely to arise when things go wrong and expert assistance is required? Isn't this both the strength and the weakness of this type of drier?

A. *The availability of servicing facilities is probably more important to the farmer than price. Adequate literature and instruction books written specifically for the user are very important and mobile drier manufacturers have to pay special attention to this aspect of their business.*

**Dr T C Ashworth (University of Birmingham)**

Q. Is agricultural grain drying by microwaves really feasible for the UK? Experience in other industries with high value output suggest that as a drying technique it is rarely economic and I believe it is unlikely to be so in grain drying. How do electricity and gas prices in the UK and USA compare?

A. *The technique was only briefly mentioned and is certainly not advocated now, but is certainly an interesting development. I do not have cost figures for USA fuels but in UK gas is now a buyer's market with large discounts — but the picture is complicated by demurrage and rental charges.*

**Mr K Perch-Nielsen (Moray Firth Maltings Ltd)**

Q. The crop is handled fairly roughly in the augers of mobile driers. Has the speaker any figures of damage and loss of germination attributable to this rough handling?

A. *No specific work has been carried out to assess damage but I would expect to hear fairly quickly from current users if this was a problem. The augers used are large — 8 inch diameter for loading and a 12 inch diameter in a 14 inch diameter casing for recirculation — and therefore unlikely to cause damage. In some crops there is an upper limit to the moisture content for safety.*

**Mr A Langley (East of Scotland College of Agriculture)**

Q. What is the effect on fuel efficiency of not using the recirculating auger during drying but only using it during the cooling period?

A. *The effect is not known — because it is not a recommended practice. The auger will contain 1.25 t of grain and the mechanical problems associated with repeated starting would be severe. By observing the current operating procedures, 1200 t of grain dried per tonne of gas with a 4-5% moisture content reduction.*

**Mr S Salisbury (Drymor (UK) Ltd)**

Q. Various comments have been made on the Drymor process — particularly that the 15 second cycle time is too short. The 15-18 second cycle time for drying/sweating has been arrived at after a great deal of measurement on prototypes in the USA, and it is effective. High temperature drying does not necessarily cause germination damage if used correctly.

A. *No reply given to this observation.*

## Questions following Paper 3, (KWE Bindloss — Developments to assist with drying and storage of grain in silos and on-floor or systems)

**Mr James T Turney (Farmer)**

Q. Is it possible to avoid overdrying the lower layers and underdrying the top layers (which are sampled by the merchant) in bulk floor drying and storage systems?

A. *The answer lies in better control systems which will monitor the progress of drying and so ensure that the average moisture content is correct with the minimum gradient.*

**Mr T A Oxley (Protimeter Ltd)**

Q. Dew point meters are available for accurately measuring humidity, but is the extra money spent on these sophisticated systems worthwhile?

A. *In general, yes, there is considerable* *scope for better control systems when drying valuable crops.*

**Mr P H Bailey (Scottish Institute of Agricultural Engineering)**
Q. The SIAE is working on the problem of moisture distribution in the grain in low temperature driers.

**Mr W L Hearle (R A Lister & Co Ltd)**
Q. Would the speaker comment on using a) fans only b) fans plus heat derived from burning fuel c) fans plus heat derived as waste heat from the engine powering the fan? In passing, I am bound to comment that there is too much worry amongst operators about putting moisture back into the grain at night — fans should be run all night. This will also lead to reduced moisture content gradients.

A. *If heat is necessary it must be cheap. Fans should be run at night, particularly in the early stages of drying, but beware of the noise pollution problem on local residents.*

**Mr G T Sampson (Alvan Blanch Development Co Ltd)**
Q. The cost of continuous flow driers plus loose storage is no greater than on-floor storage drying. Not only does floor drying and storage require a higher degree of management skill, it also requires a larger building area because of the limitation on depth of storage for satisfactory drying.

A. *There is probably little difference in cost/tonne of these two systems.*

## Questions following Paper 4, (P A Webb — Development regarding co-operative cereal storage and drying)

**Mr H J Carnall (Bonser Engineering Ltd)**
Q. What would be the extra cost incurred to make the unit appear less obtrusive on environmental grounds?

A. *This is a particularly corrosive site and a number of points were tried without a great deal of success. Some planning problems did arise on this site. Alternatives would be to use PVC coated steel or slip from concrete, both of which would be more expensive.*

**Mr S P Carter (SCATS Ltd)**
Q. What likelihood is there of co-operative storage completely replacing on-farm storage?
A. *This certainly reflects the present trend but it is difficult to envisage the complete disappearance of farm storage.*

**Mr G J Sampson (Alvan Blanch Development Co Ltd)**
Q. Is not grain handling to such co-operative complexes a major problem particularly in popular tourist areas?

A. *This is one of the more contentious aspects of large grain stores.*

## Questions following Paper 5, (O T Griffin — Storage and conditioning of malting barley)

**Mr A W Galloway (Law-Denis Engineering Ltd)**
Q. I have four questions. Q1. What evidence is there for storing grain at 33°C at 12% moisture content or above in order to break dormancy?

A1. *May be satisfactory but there can be problems during cooling with condensation and crusting.*

Q2. Why store grain at 50°C for a fixed number of days?

A2. *Grain was held at 50° C for 3 days in laboratory tests in order to break dormancy. Commercially, grain from a batch drier will only be at 25° C to 30° C.*

Q3. Is the grain moisture content reduced below 12% on cooling?

A3. *Timing is very important because grain at these low moisture contents is very hygroscropic and tends to adsorb moisture.*

Q4. Is there any evidence of taint or toxicity when using direct fired driers?

A4. *Contact time is short and levels are very low.*

**Mr T A Oxley (Protimeter Ltd)**
Q. Why do maltsters not accept the ISO standard for moisture content determination?
A. *After a great deal of discussion the problem is still unresolved. The ISO standard of 130° C for 2 hours on finely ground material specifically excludes malting barley. Care should be exercised in interpreting experimental results because there can be a moisture content difference of 1½% when the malting standard of 105° C for 5 hours is used.*

**Mr C C Simpson (Carier Ltd)**
Q. Would the speaker modify the air drying temperatures if farmers used mixed flow driers?
A. *Drying temperatures are so critical that it would be too dangerous.*

# Book

## Mechanism Design — an introductory text

THE popular image surrounding the design of linkages and mechanisms is that of a complicated and esoteric subject area best avoided if at all possible. Molian, however, in his book on mechanism design does much to lay any such ideas one might have about this subject.

The essential feature of linkages are first explained with good practical examples. We are then introduced to terms and definitions and progress to the direct synthesis of mechanisms.

Design techniques for 4-bar and 6-bar linkages are introduced, discussed and explained with examples. Great use is made here and in later parts of the book on graphical methods of solution which the author recommends as they are quick and accurate enough for most purposes. He does not avoid analytical solutions, however, and presents them as a preferred alternative to graphical solutions in some instances. The book concludes with very useful chapters on forces in linkages, and gear trains and differentials.

In producing this book Molian has taken solutions and techniques for mechanism design which have hitherto been almost exclusively in the domain of the expert and has presented them in a way which can be used, understood and enjoyed by designers and students.

*Mechanism design an introductory text, by S Molian. Cambridge University Press. Hard cover (SBN 0 521 23193 0); paper back (SBN 0 521 29863 6).*

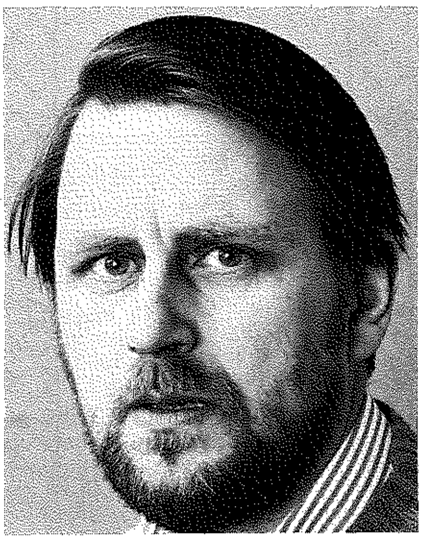
*BMDW*

# Thermodynamics of air flow in deep bin drying at near ambient temperatures

**W J Lamond**

**Abstract**

THIS is a formal presentation of the paper given at the first meeting of the Crop Drying and Storage Group. A theoretical analysis of the exchange of energy as air flows through a drying bed is compared with the data from an experiment carried out on a deep bed of grain ventilated with air at constant dewpoint and dry bulb temperatures. It is shown that while all the energy supplied eventually appears as heat, the temperature rise takes place in the fan and ducting and not in the drying bed.



## Introduction

IN medium and high temperature drying, most of the energy used is supplied as heat. The fan energy, if not negligible, is relatively small and there is little interest in considering exactly how it is dispersed. However, in near-ambient drying of crops without supplementary heat, energy is supplied only to drive the fan. Even when the drying air is slightly heated by electrical elements or gas or oil burners, the fan energy comprises a substantial proportion of the total supplied.

Normally, air for drying is guided over the motor or engine driving the fan before being blown into the crop. Even an efficient electric motor can contribute a temperature rise of part of a degree Kelvin, while an internal combustion engine can contribute a rise of several degrees Kelvin. In addition, the fan itself causes an increase in air temperature, partly by approximately adiabatic compression of the air, partly by friction between the air and fan blades and casing, and partly by turbulence. This is readily demonstrated by the results from the carefully controlled experiments of McPherson and Hinsley.[1] The air which leaves the fan, slightly warmed above ambient temperature by these losses, possesses kinetic energy due to its mass and movement, and potential energy due to its increased pressure. The rate of supply of energy in these forms is commonly known as the "air horsepower". The balance between kinetic energy and pressure energy is modified by passing through ducts of varying cross-section, but in all near-ambient driers the air enters and leaves the grain at low velocity implying negligible change in kinetic energy, whereas the static pressure differs appreciably between entry to and exit from the crop bed.

It has sometimes been supposed that the pressure loss through the crop is the result of dissipation of energy through friction. If this were so, the airpower would be converted to heat which would be available for drying. However, consideration of the elementary theory of the throttling of gases suggested that this supposition could not be justified. More detailed thermodynamic analyses were therefore made, and an experiment carried out to check theoretical predictions.

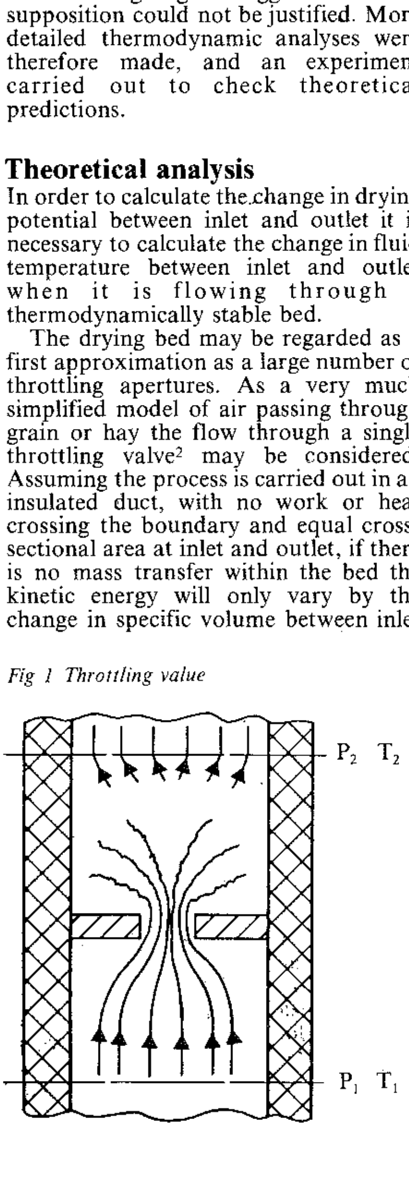
*Mr W J Lamond, Crop Drying Section, Scottish Institute of Agricultural Engineering. Refereed paper.*

## Theoretical analysis

In order to calculate the change in drying potential between inlet and outlet it is necessary to calculate the change in fluid temperature between inlet and outlet when it is flowing through a thermodynamically stable bed.

The drying bed may be regarded as a first approximation as a large number of throttling apertures. As a very much simplified model of air passing through grain or hay the flow through a single throttling valve[2] may be considered. Assuming the process is carried out in an insulated duct, with no work or heat crossing the boundary and equal cross-sectional area at inlet and outlet, if there is no mass transfer within the bed the kinetic energy will only vary by the change in specific volume between inlet and outlet. It should also be noted that the kinetic energy term is a very small proportion of the total energy supplied. For a typical value of absolute velocity through the bed of 0.25 m/s the kinetic energy is $3.1 \times 10^{-5}$ kJ/kg whereas the enthalpy will be 1.005 kJ/kg for every degree Kelvin above the reference temperature. However as the fluid passes through the restriction the increase in kinetic energy must result in a drop in enthalpy.

*Fig 1 Throttling value*




After the restriction, the original enthalpy will be re-established as the kinetic energy is dissipated by intermolecular friction and the average velocity is reduced to its original value. Taking the fluid as an ideal gas, the basic steady flow energy equation is

$$h_1 + \tfrac{1}{2}C_1^2 + gZ_1 + Q - W = h_2 + \tfrac{1}{2}C_2^2 + gZ_2$$

From the conditions stated above and neglecting the kinetic and potential energy terms the equation reduces to,

Enthalpy at entry = Enthalpy at exit

$$h_1 = h_2$$

$$u_1 + p_1 v_1 = u_2 + p_2 v_2 \quad (1)$$

$$c_V T_1 + R T_1 = c_V T_2 + R T_2$$

$$T_1 = T_2$$

Thus for an ideal gas the reduction in static pressure is accounted for by the increase in specific volume.

A better representation of a bed of grain with a real gas, is given by the porous plug experiment devised by Joule and Thomson.[3] Considering a similar steady state condition as shown in fig 1, fig 2 represents the flow through a porous plus with frictionless pistons moving with the same velocity as the gas. For a mass of gas forced through the plug the net work done by the system, is

$$W = p_2 V_2 - p_1 V_1 = m(p_2 v_2 - p_1 v_1) \quad (2)$$

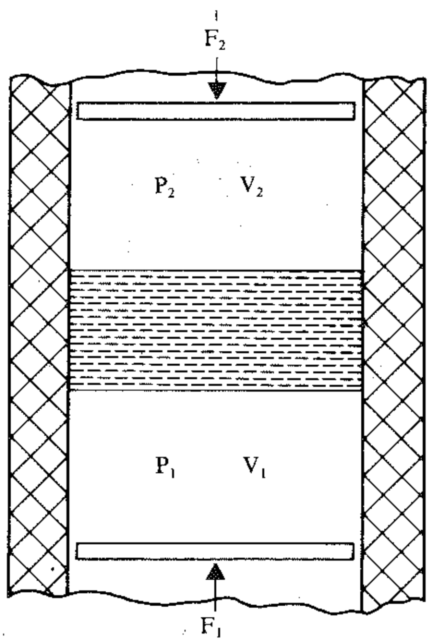



*Fig 2 Porous plug*

This must equal the change in internal energy of the fluid,

$$U_1 - U_2 = m(u_1 - u_2)$$

$$m(u_1 - u_2) = m(p_2 v_2 - p_1 v_1) \quad (3)$$

$$u_1 - u_2 = p_2 v_2 - p_1 v_1$$

This is identical to equation (1) developed for an ideal gas. Thus the change in internal energy is equal to the change in the product of pressure and specific volume. Using a suitable equation of state the relationship between change of pressure and change of temperature can be derived.

Van der Waal's equation of state,[3] is

$$(p + \frac{a}{v^2})(v - b) = RT \quad (4)$$

$$p + \frac{a}{v^2} = \frac{RT}{(v - b)}$$

$$pv = \frac{RTU}{(v - b)} - \frac{a}{v}$$

$$pv = RT(1 - \frac{b}{v})^{-1} - \frac{a}{v} \quad (5)$$

$$(1 - \frac{b}{v})^{-1} = 1 + \frac{b}{v} + \frac{b^2}{v^2} + \cdots \quad (6)$$

from (5) and (6)

$$pv = RT + \frac{(RTb - a)}{v} + \frac{RTb^2}{v^2} + \cdots \quad (7)$$

Using typical values for T and , and a tabulated value[4] of b, the third term of equation (7) is less than $2.10^{-6}$ of the first term. For practical purposes equation (7) can be reduced to:

$$pv = RT + (\frac{RTb - a}{v}) \quad (8)$$

Combining equations (3) and (8) and using $c_v = c_p - R$ we can show

$$T_2 = T_1 + \frac{2a - RT_2 b}{c_p v_2} - \frac{2a - RT_1 b}{c_p v_2} \quad (9)$$

and from (7) (10)

$$v_1 = \frac{RT - \sqrt{(RT)^2 + 4p(RTb - a)}}{2p}$$

Knowing the inlet conditions $v_1$ can be calculated from (9), and if it is assumed that an adiabatic expansion takes place through the bed for a first approximation for $v_1$, say $v_2 = v_1 (p_1/p_2)^{1/1.4}$

and as a first approximation $T_2 = T_1$ equations (9) and (10) can be solved numerically for the exit temperature $T_2$.

## Experimental Work

Drying experiments are not adequate to investigate fully the dissipation of energy because the mathematical simulations are not yet quite good enough. However, if no drying is taking place, ie if the air supplied is in thermal and moisture equilibrium with the grain, then there can be no contribution of drying to change in temperature through the bed.

In order to check the predicted change in air temperature an experiment was therefore carried out in an insulated drying bin, after the conclusion of a drying experiment[5] in which the moisture content of grain in the lower section of the bed was in equilibrium with the incoming air. Ventilation was continued, at the controlled dewpoint and dry bulb temperatures, until the complete bed was in equilibrium with the air. Fiv thermocouples were connected in serie differentially between inlet and outlet o the bed, as shown schematically in fig 3 The outlet junctions of th thermocouples were placed 300 mn below the grain surface to reduce an change in temperature due to radiation

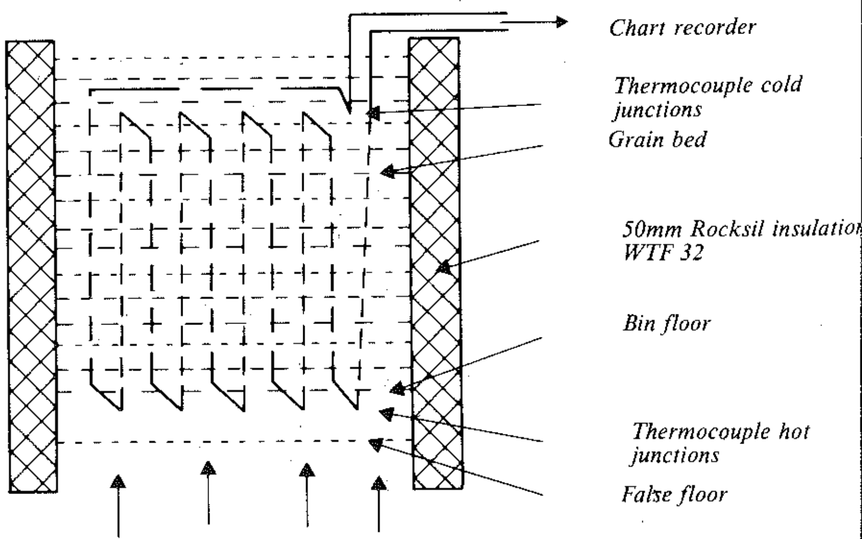
Gradually the temperature dro between inlet and outlet was reduced t approximately 0.3 K with a range 0.2 t 0.5 K. The variation was mainly due t the time taken for grain higher up the bi to respond to slight changes in inle temperature. After a further eight day continuous running the experiment wa terminated. Throughout this time th differences in temperature between inle and outlet remained within the range 0. to 0.5 K, apart from deviations due t faults in the automatic temperatur control system.

The results show reasonable agreemen between measured and calculated result bearing in mind the difficulties o measuring small temperature changes. I the hypothesis that all the static pressur energy at inlet is converted to heat b friction as the air flows through the be were correct, then a static pressur reduction of 1.5 kPa through the bed equivalent to a loss of 1.5 kJ for ever cubic metre of air or 1.25 kJ/kg of ai and taking the specific heat of air as 1.00 kJ/kg a temperature rise across the bed o 1.2 K would be expected, in contrast t the measured 0.3 K drop. There is clearl no support for this hypothesis an calculations of the drying process shoul not credit the static pressure energy a entry to the drying potential of the air.

## Conclusions

In a well designed drying system wher the waste heat of the motor is collected b the drying air it is reasonable to assum all the energy supplied to the moto results in an equivalent rise in ai

*Fig 3 Drying bin*



Average values of the test conditions over the final 24 hours of the experiment are listed below:—

| | |
|---|---|
| Cross-sectional area of bed | 1.478 $m^2$ |
| Air mass flow | 0.208 kg/s |
| Mean inlet temperature | 293.45 K |
| Mean inlet dewpoint temperature | 286.4 K |
| Room temperature | 288.15 K |
| Inlet air pressure ($p_1$) | 102.6 kPa |
| Outlet air pressure ($p_2$) | 100.9 kPa |
| Measured temperature difference ($T_1 - T_2$) | 0.3 K |
| Calculated temperature difference due to heat loss by condution through the insulation | 0.17 K |
| Calculated temperature difference due to expansion through bed | 0.01 K |
| Total calculated temperature difference | 0.18 K |

$$\text{Change in entropy} = c_v \ln \frac{T}{T_0} + R \ln \frac{v - b}{v_0 - b} = 116.7 \text{ J/kg}$$

temperature, neglecting any heat loss through the ducting. This temperature rise should be included in mathematical models of drying systems but it should be noted that it occurs in the fan and high velocity ducting, and there is no further increase in air temperature as static pressure decreases through the bed.

**Nomenclature**

| | | |
|---|---|---|
| a | — Constant for Van der Waal's eqn of state | $m^4/kmol^2$ |
| b | — Constant for Van der Waal's eqn of state | $m^3/kmol$ |
| C | — velocity | m/s |
| $c_p$ | — specific heat at constant pressure | $J\ kmol^{-1}\ K^{-1}$ |
| $c_v$ | — specific heat at constant volume | $J\ kmol^{-1}\ K^{-1}$ |
| g | — gravitational acceleration | $m/sec^2$ |
| h | — enthalpy | $J\ kmol^{-1}\ K^{-1}$ |
| m | — mass flow | kmol/s |
| p | — pressure | Pa |
| Q | — heat input per unit mass flow | J/kmol |
| R | — universal gas constant | $J\ kmol^{-1}\ K^{-1}$ |
| S | — entropy | $J\ kmol^{-1}\ K^{-1}$ |
| T | — absolute temperature | K |
| U | — absolute internal energy | J |
| u | — specific internal energy | J |
| V | — absolute volume | $m^3$ |
| v | — specific volume | $m^3/kmol$ |
| W | — work output per unit massflow | J/kmol |
| Z | — height above reference level | m |

Subscripts

1 Inlet conditions
2 Exit conditions

## References


1 **McPherson M J, Hinsley F B.** Thermometric testing of fans. *Heating and ventilating engineer,* October 1963, 175-181.

2 **Rogers G F C, Mayhew Y R.** *Engineering thermodynamics work and heat transfer.* Longmans, Green and Co, London, 1957, pp 96, 104.

3 **Sears F W.** *An introduction to thermodynamics, the kinetic theory of gases and statistical mechanics.* Addison-Wesley Publishing Company, Reading, Massachusetts, 1959, p 72.

4 **Kaye G W C, Laby T H.** *Tables of physical and chemical constants and some mathematical functions.* Longmans, Green and Co, London, 1952, p 46.

5 **Lamond W J, Bowden P J.** Drying two metre depths of Midas barley with near ambient air, harvest 1979. Dep Note SIN/308, Scot Inst agric Engng, Penicuik, 1980 (unpubl).

# Energy saving in grain drying

## B Fraser-Smith

> **Background**
> *Aylescott Driers was founded in 1968 to produce a high quality concentrated winter feed for a 200 cow dairy herd, but eventually the grass drying operation displaced the dairy herd on this 325 ha farm in North Devon. Energy costs figure very prominently in the profitability of the enterprise and the author's attempts to improve energy efficiency will be of interest to many readers.*
> *Editor*

### Summary
HAVING expanded production from 500 to 4000 tonnes/annum in two high temperature single pass rotary drum driers, and changing to gas firing in 1974, the owner sought ways of reducing energy (and costs) per tonne of product.

Partial field drying was optimised but many other ideas required a detailed study of the drying process. In 1978, with South West Gas and Midlands Research Station, surveys showed the energy saving potential in the plant.

An overall saving in energy of over 40% has been achieved reducing the fuel consumption from 148 to 76 therms per tonne, representing an annual saving of some 280,000 therms.

### The grass drying plant
THE grass driers are of the high temperature, single pass rotary drum type manufactured by Van Den Broek, of Holland, coupled to a direct fired air heating furnace at one end, and a separating cyclone and exhaust fan at the other.

The exit drier temperature, which is controlled at 115°C, determines the drier entry temperature, this is usually between 500°C and 600°C according to the drying load.

Fresh, short chopped grass between 65% and 90% moisture content, is dropped into the neck between the furnace and the drier and is drawn through the drier drum by an air flow created by a large exhaust fan situated downstream of the cyclone. The drum slowly rotates and is internally baffled to promote the drying process, after which the grass and waste gases are separated in the cyclone.

The moisture content of the dried grass is 12%, and is now milled, pelleted and stored for sale mainly during the winter months.

Prior to drying, each field of grass is analysed for protein and fibre content so that after processing it can be stored according to grade. There are three grades required by livestock farmers, having a declared minimum protein content of 14%, 16% and 18%, all produce being subject to control under the Feeds and Fertilizer Act.

The two driers installed have a capacity of 2½ t/h water evaporation each, providing a total production capability of 4000-4500 tonnes/annum.

The furnace was originally oil-fired but was changed to gas-firing in 1977 following reconstruction of the furnace using the Stordy Hauck Wide-Range duel fuel burner unit with a nominal rating of $10 \times 10^6$ BTU/h.

### Economics
In 1974, to dry grass from 80% to 10% moisture content required 148 therms/tonne and the viability of the process was in question. Since the initial moisture content can greatly influence the heat required for drying, a process of partial drying in the field was tried and by 1976 the fuel consumption was reduced to 115 therms/tonne. This partial drying process could not be extended further because grass suffers both physical and nutritional loss if left longer in the field, and is subject to all weather conditions.

Several ideas to improve efficiency, in particular to utilise the low grade exhaust heat, were examined.

A report to the British Association of Green Crop Driers included evidence from Aylescott Driers and referred to the difference in the relative efficiencies between gas and oil firing. Following discussions with South West Gas it was agreed to carry out a detailed test of a drier using both oil and gas fuels. The principal figures from the test are given in table 1 below and indicate the variation and influence of the water content of grass on the drying time and energy consumption.

**Table 1 Results of three test runs on grass drier**

| | *Gas* | *Oil* | *Gas* |
|---|---|---|---|
| Wet grass feed, t | 25.4 | 21.6 | 15.3 |
| Dry grass produced, t | 3.7 | 3.9 | 3.8 |
| Water removed, t | 21.7 | 17.7 | 11.5 |
| Heat input, t | 72.2 | 59.6 | 42.4 |
| Head required, M Btu | 50.8 | 41.4 | 26.8 |
| Duration of run, M Btu | 7.45 | 7.38 | 4.67 |
| Efficiency, % | 70.3 | 69.4 | 63.2 |

The report of the test listed the following parameters that influence the process efficiency:—

i) heat input rate
ii) load throughput rate
iii) grass moisture content at start and at finish
iv) excess air levels
v) ambient humidity
vi) duration of run
vii) dewpoint of combustion products

The heat required rises dramatically as the percentage moisture in the wet grass rises. As the moisture content rises from 76% to 86% the volume of gas required doubles, thus a method to control the moisture in the wet grass could pay substantial dividends. The test report also quantified the energy available in the flue gases above dewpoint at approximately 8% of the gross heat input.

### Innovation
In 1979, Mr Fraser-Smith saw a system that could be economically viable. A screw press to extract some of the juice from the grass before drying, thus reducing the drying heat load, and the novel use of an evaporator to condense the juice for re-injection into the product were investigated on the Continent in 1979.

Moisture content of fresh cut grass varied from 65% to 90% although the seasonal average was 78%. It had been established that the nutritional value of juice in grass above 80% moisture was very low and the test report showed that heat requirements were doubled when the moisture content rose by ten percent.

The procedure now followed is to throw away the juice above 80% except that required by the evaporator, the screw press on average removing some 5% to 7% of the moisture content.

The juice is collected and condensed at a 4:1 ratio in the new evaporator utilising the exhaust gases from the drier under carefully controlled conditions.

In conjunction with the late Mr Gordon Shepperson of the National Institute of Agricultural Engineering, who specialised in the chemistry and engineering of grass drying, it was found that the grass juice proteins are extremely sensitive to temperature and are damage at temperatures above 55°C, thus normal evaporators using the exhaust gases would not be satisfactory.

A single effect, non-vacuum type evaporator was developed by Alfa Laval of France, whereby ambient air is drawn in with the juice passing through the tubes of the evaporator which are heated by the exhaust gases on the outside. This allows the juice to give up its moisture and saturate the air, and by controlling the exhaust gases and the ambient air it is quite easy to achieve low temperature evaporation to avoid damage to the grass proteins.

The condensed juice is returned and mixed with the pressed grass and dried in the normal manner.

This evaporator is the first of its type to be installed anywhere in the world on this process. It has the ability to condense heat sensitive juices in bulk, and whilst vacuum type evaporators are commonly used on larger heat sensitive evaporation processes, the volume of product in this application makes the capital cost of vacuum evaporation non-viable.

Nevertheless there is a wider application potential within green crop drying and the installation at Aylescott Driers has attracted EEC Development Aid from Brussels under the Commission's Energy Demonstration Project.

In parallel with this development Mr Fraser-Smith and South West Gas were pursuing the idea of re-circulation of the drier exhaust gases. A re-circulation duct was installed to return a proportion of the exhaust gases from the drier outlet to the ingoing air to the furnace. As well as re-cycling waste heat to the furnace this action also increased the latent heat content of the exhaust gases entering the evaporator, thus increasing its capacity and adding a further 3% to 5% efficiency to the process. It was found possible to re-circulate some 25% to 30% of the drier exhaust gases, representing about an 8% saving in fuel.

## Savings

1. A 20% saving through pressing out the excess moisture and using the latent heat in the exhaust gases to condense the grass juice. Since the drier work load is now reduced it is possible to increase the production rate if required.
2. A further 8% saving by re-cycling some 25% to 30% of the exhaust gases from the drier exhaust stack to the furnace. This also increases the latent heat value of the exhaust gases to the evaporator adding a further 3% to 5% efficiency to the process.
3. The physical act of pressing the grass creates cell rupture. This has two effects.
   - i) It allows some internal cell moisture to be removed as juice for evaporation
   - ii) The rupturing allows the normally well protected cell moisture that remains to be more easily dried. Trials have shown the average fuel saving to be 15% due to this action.

   To this must be added the effect of reduced drying times in terms of electrical, labour and maintenance costs.

An overall saving in energy of over 40% has been achieved, reducing the fuel consumption from 148 to 76 therms/tonne, representing an annual saving of some 280,000 therms.

The new technology and improvements made have not complicated the plant, it is simple to run and no additional staff has been necessary. It is flexible in performance to permit increased production or to produce the same tonnage in less hours, thus coping with the vagaries of nature in the most energy efficient way.

# Effective choice and use of agricultural tractors

## John Matthews

### 1. Introduction

FARMS are so variable, both in size and nature of the enterprise, that it is quite impossible to make a generally applicable recommendation on choice and use of tractors. Nevertheless, it is considered worth outlining those factors which should be taken into account by the user and explaining their relevance to the types of decisions that have to be made. The choice of tractors has never been wider than now, and as well as a power range from approximately 10 kW to 300 kW, a variety of specialised vehicles are available having low ground pressure properties, characteristics suitable for materials handling, dimensions suitable for use in orchards, or a ground drive system suitable for high tractive uses. In addition, an increasingly wide range of specialised self-propelled machines have appeared which generally compete with the tractor in the individual task such as harvesting, materials handling, spraying or fertiliser distribution.

This paper sub-divides the decisions into those affecting the choice of tractor to be purchased, and those affecting the use of the tractor on the farm. In considering perhaps the most basic aspect, the power capacity of the tractor, it is important to be clear that a number of different power ratings are often quoted, the main differences being due to the point at which the power is measured and the environmental conditions under which it is measured. In fig 1 the various power levels which might be quoted for the same tractor are compared. These

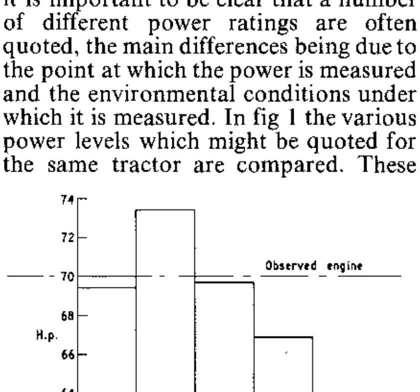



*Fig 1 Comparison of different methods of rating horsepower*

data include engine output power, power take-off power, and draught power available from the drawbar. The two values shown for the engine, after the method defined by the German Standards Organisation (DIN) and the


*John Matthews is head of the Tractor and Cultivation Division, NIAE, Silsoe, Bedford.*



*Paper to IAgrE, Scottish Branch, February 1982.*


American Society of Automotive Engineers (SAE) are different, partly because of the different auxiliaries specified to be present on the engine in the two cases, and partly due to differences in the defined climatic and atmospheric conditions at the time of the test.

### 2. Choice of tractor

#### 2.1 Size

The required power level is clearly dependent on both the size of the farm and the nature of duties required of the tractor. It is reasonable to make the choice on the basis of best likely economic performance on the choice of that particular size. As an example which indicates the way that cropping pattern and soil type can affect tractor choice, table 1 shows typical results from operational research studies at NIAE in which the net profit of a 200 hectare arable enterprise is calculated with various machine systems[1]. Three principles, which appear to have a more general validity, arise from this comparison.

i) On an enterprise growing cereals only, the optimum size of tractor for maximum profit varies with soil type. On a difficult soil where more effort is required, a more powerful tractor gives a greater predicted return. On the farm with easier soil, the lower power tractor appears preferable.

ii) When root crops are grown, and because of their greater labour requirements at harvest, it appears to be more economic to operate with smaller tractors. This presumably is because the men are available to drive them.

iii) The differences arising from choice of tractor size are small, and are, for example, much less than the differences arising from the use of different types of cultivating soils.

This latter feature, the smallness of the differences, has also been shown in work reported by Zoz[2]. In his paper he predicted for use in typical British arable conditions, that the tractor of approximately 85 kW was likely to give optimum economic performance. However, he also calculated size range for which the operating costs would be no more than 5% greater, and found that this size range varies from as little as 40 kW to as much as 200 kW.

#### 2.2 Engine and transmission

Other than power level the two most significant characteristics of the engine are probably the torque characteristics and the fuel economy. A good "torque backup" is required for agricultural tractor use to ensure that the engine is capable of continuing to work when the load is increased by encountering tougher patches in the field, or by temporary increases in loading of, for example, a forage harvester when used on the power take-off. On encountering an increase in load when working already at high power the engine quite naturally reduces speed. It is important under these conditions that the engine characteristics provide an

**Table 1 The predicted influence of tillage method and tractor size on gross profit margins under UK conditions**

| | *Profit margin, £/ha* All cereal, heavy | All cereal, light | Cereal/Sugar beet, heavy |
|---|---|---|---|
| *Traditional tillage* | | | |
| 56 kW tractor | 114 | 150 | 121 |
| 104 kW " | 115 | 148 | 120 |
| *Chisel plough seedbed prep, drill* | | | |
| 56 kW tractor | 126 | 152 | 132 |
| 104 kW " | 126 | 151 | 130 |
| *Rotary dig, combined seedbed prep and drill* | | | |
| 56 kW tractor | 136 | 156 | 141 |
| 104 kW " | 138 | 157 | 139 |
| 56 kW tractor with trailed 104 kW power unit | 135 | 157 | 139 |

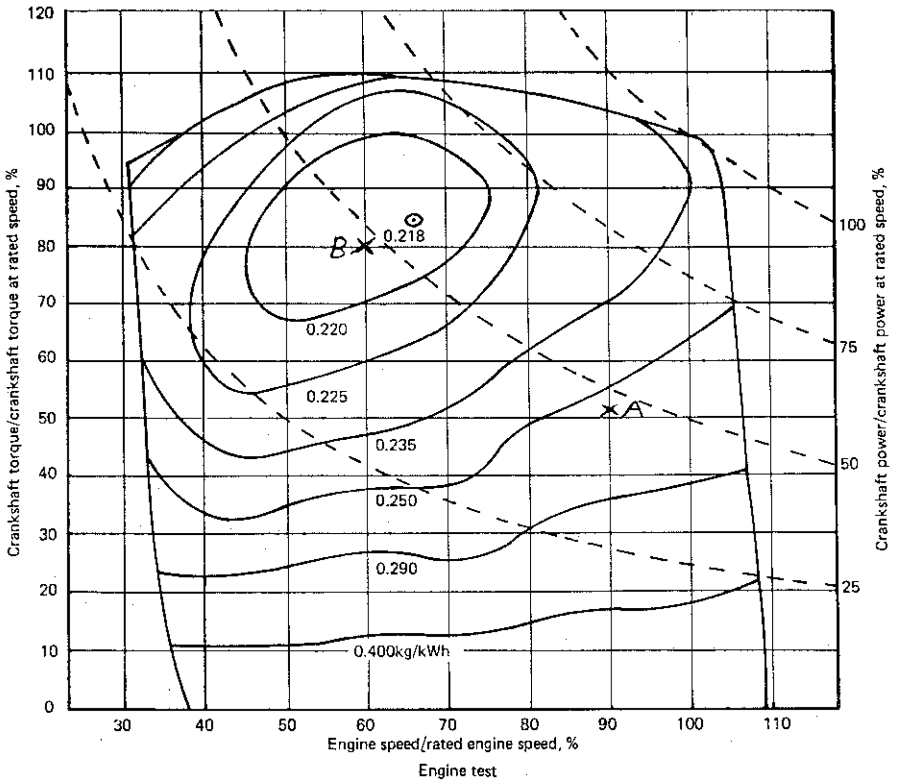



*Fig 2 Fuel economy measured over operating range of an engine*

increase in torque (fig 2) so that traction or pto power may be maintained to overcome the temporary increase in loading. With increases in fuel cost, the fuel economy of an engine has become of somewhat increased interest, although it is still a relatively small part of total operation costs. It is important to realise that the specific fuel consumption of an engine varies greatly over the full operating torque and speed range, and further that the best fuel economy does not necessarily occur at the same point on this characteristic with different models (fig 3). The choice of a single point on the

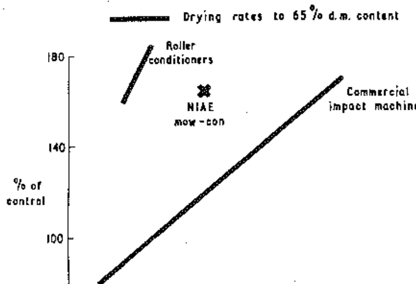



*Fig 3 Influence of grass mowing and conditioning machine type on rate of drying of crop and on power needed (kW per metre width of cut or treatment)*

characteristic to express fuel economy, be it the maximum power at rated speed, maximum power at standard pto speed, or some proportion of power below the maximum is therefore somewhat limited. The most common figures quoted would appear to be the economy at maximum power in that this is the point at which most fuel is inevitably used, and perhaps the economy at 85% of power at standard pto speed, which is often thought to represent perhaps the most typical operating condition of the tractor engine. At these points there is something to the order of 20% difference between available models of tractor[3]. Again, one must be clear that a tractor with sophisticated auxiliaries such as power steering, large quantities of hydraulic power, or other auxiliaries, may often show a worse fuel economy than a less sophisticated tractor, simply because of the power absorption of these auxiliaries. This applies particularly to articulated vehicles where much power is required for steering.

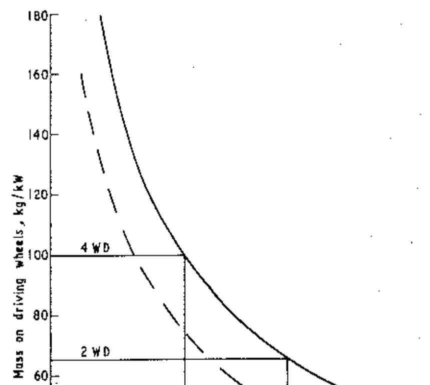
The choice of transmission will again depend on service. For a tractor required for sustained power field work, such as tillage or forage harvesting work, a mechanical transmission will give greater efficiency than a hydrostatic type. The hydrostatic transmission may well come into its own for handling a tractor where there are to be frequent changes of direction and speed. Facilities for changing gear ratios on the move generally permit more efficient field operation in that the driver is happy to adjust the ratio continually on such tasks as baling or mowing where there is variation in crop or variation in the roughness of the surface, for example. As the proportion of use of pto powered machinery continues to increase slowly, the importance of a large number of gear ratios being present also increases. This is because the engine operating speed tends to be established at that speed necessary to provide standard pto speed. The choice of gear, and hence forward speed of travel is thus determined by the power availability. If this is just insufficient for one gear then the next lower gear will need to be chosen and, if the difference in ratio between these two is large, a considerable and unnecessary reduction in speed may result. In general gears should be well spaced and the speed ratio from one to the next be no more than 30% different.

### 2.3 Ground drive

The track-laying tractor still has much to offer under appropriate circumstances. The tractive efficiency is normally of the order of 90% compared with 60-70% for a wheel drive system. Studies a few years ago by NIAE and MAFF showed the average maintenance costs of the two types of system to be roughly equal[4]. It is clear however that the wear and hence maintenance cost of a track is likely to be greatest on a soil with a relatively high silica content, whereas the maintenance cost of pneumatic tyres would be highest in a soil containing many flints. The metal track provides, in general terms, a ground pressure of the order of 0.3 bar, compared with equivalent pressure of pneumatic tyres of 0.8-1.1 bar. Against this the mobility over public roads and even longer distances on the farm of a tracked vehicle is clearly grossly inferior to that of a wheeled vehicle.

When a decision has been made in favour of a wheeled vehicle the choice of 2-wheel drive or 4-wheel drive has to be made. Work by Dwyer *et al*[5] has shown that a 4-wheel drive tractor with smaller driven wheels at the front is likely to give a tractive efficiency and hence workrate of 7% better than the equivalent 2-wheel drive tractor. When larger equal size wheels are fitted throughout, the increase will be of the order of 15%. Advantages of 4-wheel drive would be increased where the land is sloped and benefits are provided to the stability and handling characteristics. On level land some of the advantages stated above may be lost when the comparison is made with a 2-wheel drive tractor fitted with dual wheels on its driven axle. Whatever the choice of ground drive, the importance of correct tyre choice and of correct ballasting has also been clearly demonstrated by work by Dwyer *et al*[6] and by Gee-Clough[7]. Figure 4 shows that for a tractor

*Fig 4 Mass on driving wheels required for maximum tractive efficiency at different speeds*



operating at a typical tillage speed of 5 km/h the driven wheels should carry a load of approximately 100 kg/kW installed power.

Other factors likely to significantly affect tractive efficiency are the types of tyre, namely radial ply or cross ply and the height of lugs. It has been shown that the radial ply type tyres typically increases pull available by 6% although, due to somewhat higher rolling resistance loss, tractive efficiency is not materially altered. No consistent difference in performance with height of lug has been shown over the range 10 mm to 50 mm. Above this, under most conditions, there may be some loss in performance although in the very worst conditions there can be an advantage (see table 2).

**Table 2 Relationship between maximum tractive efficiency (%) and soil state for various type lug heights**

| Soil state | *Lug height (mm)* | | | | |
|---|---|---|---|---|---|
| | 0 | 20 | 35 | 50 | 75 |
| Very good | 82 | 81 | 79 | 78 | 74 |
| Good | 79 | 79 | 75 | 74 | 70 |
| Poor | 61 | 59 | 58 | 58 | 58 |
| Poor | 59 | 61 | 59 | 60 | 61 |
| Mean values | 70 | 70 | 68 | 67.5 | 66 |

The other main characteristic of a tyre of importance to the user is the soil compaction effect[8]. In the surface soil, compaction is generally related to the inflation pressure of the tyre and hence it is an advantage to use larger section sizes which will tend to permit lower inflation pressures. There is evidence that in the sub-soil the degree of compaction is governed more by the total vehicle weight at the axle than by the actual inflation pressures. For more specialised applications dual wheels may be used permitting lower inflation pressures. Wide section tyres are available with the advantage of reducing overall vehicle width with duals, or ultra-low pressure "Terratyres" may be used, in which case inflation pressures may be down to 0.3 bar or less. Where the vehicle is to run over a growing crop it is important to consider not only the direct damage to the soil but the possibility of damage to the crop from bruising arising from slip of the wheel.

### 2.4 Ergonomics and other design features

It is a reasonable assumption that inadequacies in the ergonomics aspects of a vehicle's design can significantly reduce the performance an operator will obtain from the tractor. Evidence available for this assertion is largely circumstantial and typical of this are data shown in fig 5 where comparisons are made between the noise levels of a series of vehicles established under identical test conditions, and the mean noise level measured during work with numbers of each of these model of tractor. It is clear that although the tractors exhibit a significant difference in noise levels under the identical test conditions, these

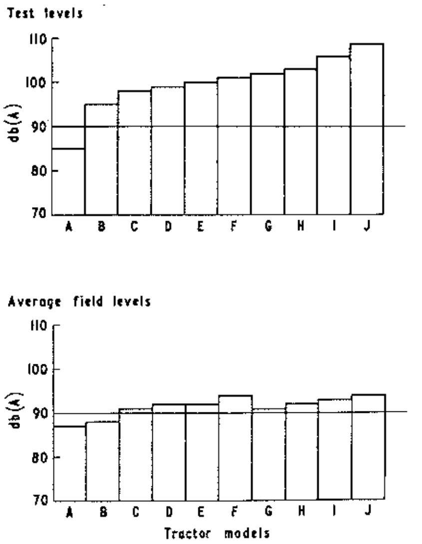



*Fig 5 Comparison of noise test levels (max noise) and levels found in field operation*

differences are considerably diminished during normal field work. The only reasonable hypothesis to explain this is that the drivers tend to use the noisier vehicles at a lower engine speed and hence a lower power level, resulting in less increase in noise over the quieter models. This would be explained by a reluctance of the drivers to put up with the higher noise levels and the result of the phenomenon would be a reduction in work output from noisier tractors. It is therefore important that the prospective purchaser takes account of the lower noise levels.

Also likely to affect the chosen working speeds is the ride vibration comfort of a tractor. Suspension seats can reduce the level which would appear with a rigid seat by up to 50% and their cost is undoubtedly repaid in comfort and resulting performance[9]. The dimensions and the positioning of the seat in respect of the controls can again affect comfort and convenience of control operation. It is a pity that despite the fact that much tractor driving work is undertaken whilst the man is turning rearwards, facilities for rearward swivel are not provided on most seats. Bottoms[10] has, nevertheless, reported work which has shown this to be both a practical and an apparently advantageous feature. In addition to the seating, the location, design (covering such things as operating mode and operating force), and the identification of controls can all make for efficient operation.

Today's tractor cab provides both security and weather protection for the driver. Legislation in many countries demands that the structure has been demonstrated to have sufficient strength to withstand crushing in the event of a tractor overturn so that the strength of the structure is not really a matter for comparison. Another aspect of safety however is the protection afforded by the cab from toxic chemicals and to a lesser degree the isolation it gives the driver from dust and plant debris. For the more hazardous chemicals it is necessary for the individual cab to be adequately tested for sealing against ingress, for effective filtering and effective pressurisation. For all chemicals however the cab can provide a useful protection if adequately pressurised and sealed, and if fitted with a ventilator incorporating correct filtration means.

The climatic environment provided by the cab will be determined both by the adequacy of heating arrangements in colder weather and the adequacy of ventilation and cooling in summer conditions. The heating tends to be relatively straightforward, whilst the avoidance of over-heating in the summer often presents more of a problem. The incorporation of air-conditioning is essential in some parts of the world and does always provide, assuming that the air-conditioning is effective, satisfactory environment despite the possibilities of high levels of radiant heat from the sun through the windows. This radiant heat load is probably the most serious snag with cabs in that the window area tends to be large and radiant heating of the operator can be affected not only by the direct sunlight through the windows but by secondary radiation from internal surfaces which become heated by the direct rays. In some cases the shape of a cab has been designed to somewhat reduce radiant loading, this being particularly so where windows slope inward to the lower ends. Tinted glass is also used to cut down heat loading but this is of somewhat restricted value in that the heat load cannot be reduced by greater proportion than the reduction in light transmission and hence vision. The use of external canopies has been proposed[11] and there is evidence that air-conditioning may be avoided providing ventilation is adequate and means are taken to reduce the radiant load.

Three other characteristics of the tractor which should be carefully considered are the hydraulic lifting force available on the three-point linkage, to ensure that this is adequate to cope with the implements used, the amount of power available from external hydraulic tappings to operate equipment such as hedge-cutters, etc and a need for more consideration, at the time of purchase or later, of using the tractor with both rear and front mounted implements for which additional linkages and power take-off shaft may be available at the front of the tractor. External to the actual tractor there is definite advantage to be seen in utilising systems of automatic couplers between tractors and implements. These provide for easy one-man coupling of the implement hence saving time and also providing increased safety for the driver who no longer has to manhandle heavy machinery.

## 3. Use of the tractor

### 3.1 Choice for the individual task

Most farms have more than one tractor and these tractors are likely to be of different power levels. A choice often has to be made as to which of the tractors should be used for a particular task. A typical situation is one in which more and less powerful models are available for jobs not requiring large power levels such as spraying or fertiliser distribution, and the temptation may often be to use the larger tractor for reasons of comfort or convenience. In table 3 the effect on fuel

**Table 3 Comparisons of the fuel consumptions of smaller and larger models of tractor employed for a lower power (11.5kW or 15 hp) task**

| *Tractor* | *Max engine power kW (hp)* | *Engine power needed for 11.5kW (15hp) drawbar power* | *Specific fuel consumption at engine operating condition kg/kWh* | *Fuel consumed per hour kg* |
|---|---|---|---|---|
| Manufacturer A, smaller | 35.6(47.4) | 16.6(22) | 0.233 | 3.86 |
| Manufacturer A, larger | 56.0(74.1) | 19.0(25.2) | 0.247 | 4.69 |
| Manufacturer B, smaller | 37.8(50.0) | 18.0(23.9) | 0.261 | 4.70 |
| Manufacturer B, larger | 66.3(87.7) | 19.5(25.8) | 0.306 | 5.97 |

consumption of making this choice is shown by typical examples. The larger model tends to consume more fuel because a greater weight has to be propelled across the field, and also because its engine, in operating at a lower proportion of maximum capacity, tends to be operated in a less efficient mode. These two factors together mean a 20-25% difference in fuel used with a difference in tractor power level of somewhat less than 2 to 1.

For efficient field operation it is important that tractor and attached implement are matched one with the other. Instructions for this are difficult to generalise but it is the author's opinion that farmers often use too wide an implement where a more narrow machine and a higher chosen forward speed would give more efficient operation.

The choice of tractor size and the implement match may influence the cost of operation perhaps by 10% in each case. A rather larger impact will be made by two other factors; by the choice of type of implement to carry out the task and by the appropriate use of implement combinations. The most obvious example of cost and power savings by choice of implement is the trend towards reduced cultivation, where there is much evidence from Patterson[12] and others that reduced tillage treatments, or more efficient tillage operations, requiring 50% or less of power of more conventional methods, can nevertheless ultimately lead to the same crop yield. Patterson[13] has also shown that cost can be saved by combining tillage operations so that labour is saved in the man traversing the field less times on the tractor. As well as the examples in arable farming of seedbed preparation and drilling, or of rowcrop spraying and planting, implement combinations may be used in haymaking where swathers and balers may be combined[14], or in sugar beet harvesting where toppers and lifters could be fitted to the same tractor.

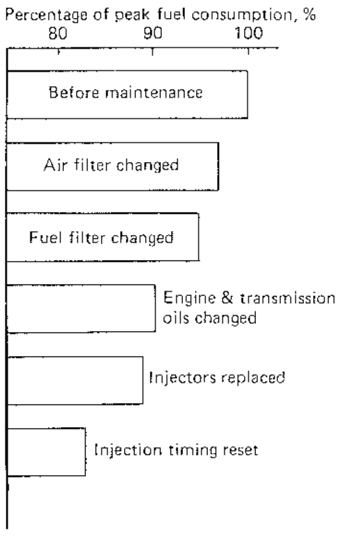
### 3.2 Driving

Power can be wasted by poor setting, lubrication and maintenance of the equipment. This applies particularly to mouldboard ploughs where draught is greatly affected by alignment adjustments and by clean and polished shares and moulboards. Fuel economy can be significantly affected by the correct choice of gear and engine speed. In general terms, the tractor should be driven in the highest gear and lowest engine speed at which it may work. The effect of this on fuel economy is illustrated in fig 3 where a typical choice might be to operate in a gear which demanded from the engine 60% of rated speed and 80% of rated torque (total power of 48% maximum), or in a gear requiring 90% of rated speed and 53% of rated torque. As will be seen from the diagram of specific fuel consumption the values of these two operating points are 0.22 and 0.26 kg/kWh respectively, and represent a difference of some 20% in fuel economy.

### 3.3 Maintenance

In an earlier paper the author quoted results of power measurements made on tractors after twelve months operational advance. As measured in the state allowed by the owners the mean power was some 88% of power when new. However, after replacement of faulty injectors and air-cleaner elements the mean power increased to 98% of the original power when new, clearly indicating the considerable loss of capacity by an accepted level of maintenance. In more recent studies by an oil company, the successive reduction in fuel consumption to yield constant power, are listed in fig 6 as various maintenance task components are undertaken. Here again a reduction in fuel consumption and hence improved fuel economy of the order of 15% was encountered over the complete range of maintenance actions.

*Fig 6 The effect of tractor maintenance on fuel consumption for a given pto power*




## 4. Conclusions

The paper has outlined a number of factors which individually affect either the cost of the operation or the fuel consumption of the vehicle in operation by a few per cent. Many of these are additive and overall can affect the cost of tractor work very significantly. The choice of technique and implement to carry out the farm task is perhaps the largest of the influences, but even when this is optimised, the other factors such as ground drive choice, implement matching, driving habits and maintenance will still be additive to it.

The general purpose agricultural tractor continues to suffer increased competition from specialised self-propelled machinery. For any given task these are likely to perform better since the tractor is a compromise necessary to provide for the extremely flexible machine which it is. Many of the factors mentioned in relation to the tractor would also, to a degree, apply to other farm vehicles. They all amount to good housekeeping and to an analytical understanding of the factors which affect the tractor performance.

## References


1 **Audsley E, Dumont S, Boyce D S.** An economic comparison of methods of cultivating and planting cereals, sugar beet and potatoes and their interaction with harvesting, timeliness and available labour by linear programming. *J agric Engng Res,* 1978 23 (3) 283.

2 **Zoz F M.** Factors affecting the width and speed for least cost tillage. *The Agric Engr* 1974, 29 (3) 75.

3 Royal Agric Soc England. Tractor Test Results 1981.

4 MAFF. Wheeled and tracklaying tractors. A joint ADAS/NIAE study of utilisation, performance and tyre and track costs 1969-70. *Farm Mechanisation Report No 21,* HMSO, London.

5 **Dwyer M J, Pearson G.** A field comparison of the performance of two and four-wheel drive tractors. *J agric Engng Res,* 1976, 21 (1) 77.

6 **Dwyer M J, Evernden D W, McAllister M.** *Handbook of agricultural tyre performance (Second Edition).* nat Inst agric Engng Report No 18, 1976.

7 **Gee-Clough D.** Selection of tyre sizes for agricultural vehicles. *J agric Engng Res,* 1980, 1, 25, 261.

8 **Soane B D.** Compaction by agricultural vehicles: A review. *Soil & Tillage res,* 1980, 1, 207 and 373.

9 **Matthews J.** The measurement of tractor ride comfort. Soc Auto Engrs, Paper 730795, 1973.

10 **Bottoms D J, Barber T S.** A swivelling seat to improve tractor driver's posture. *App Ergonomics,*. 1978 9 (2), 77.

11 **O'Neill D H.** The effects of solar energy on the thermal environment in an enclosed tractor cab. DN/E/867/02001, nat Inst agric Engng, Silsoe, 1978 (unpub).

12 **Patterson D E, Chamen W C T, Richardson C D.** Long term experiments with tillage systems to improve the economy of cultivations with cereals. *J agric Engng Res,* 1978, 25 (1), 1.

13 **Patterson D E, Richardson C D.** Bridge links for combined cultivation and drilling. *The Agric Engr,* 1981, 36 (1), 3.

14 **Tuck C R, Klinner W E, Hale O D.** Economic and practical aspects of high capacity rotary mower and mower-conditioner systems. *The Agric Engr,* 1980, 35 (1) 11.