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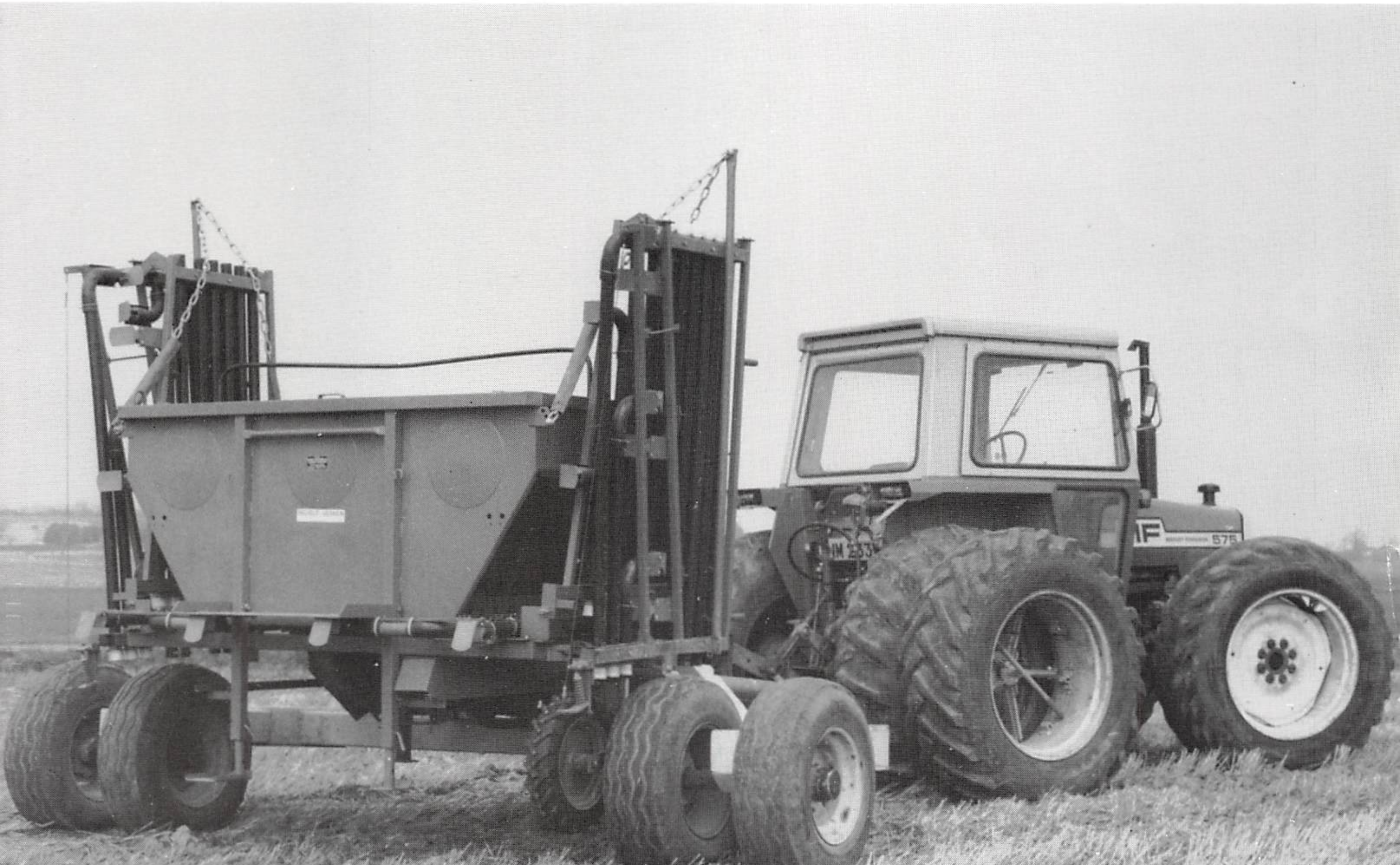

Developments in the handling and application of solid fertilisers

The Institution of Agricultural Engineers

Journal and Proceedings

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Front cover:
For low ground pressure operation, this tractor and pneumatic applicator have been fitted with additional wheels and the inflation pressure of the tyres lowered.

[*NIAE photograph*]

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Problems of harvesting raspberries by machine in Scotland — a review of progress

A M Ramsay, M R Cormack, D T Mason, B Williamson

Summary

A MULTIDISCIPLINARY approach to mechanical harvesting of red raspberries has identified the major problems. These include some aspects of the growth pattern and morphology of the raspberry, the effects of fungal infection of wounds on young canes, losses of fruit during harvest and the difficulties of discriminating between sound ripe fruit and fruit which is under-ripe or damaged. Solutions or partial solutions have been found for these problems; engineering developments have eliminated young cane damage, reduced fruit losses and improved the prospects of better discrimination. Agronomic developments offer similar benefits and opportunities of further mechanisation in raspberry culture; plant breeding has produced cultivars with flexible pedicels and fruiting laterals, easy berry abscission and superior fruit quality. It is concluded that a highly mechanised system of growing and harvesting raspberries is now available to growers should social and economic circumstances make it desirable.

1 Introduction

Attempts to harvest fruit of *Rubus* species by machine were first made about 1948 in the USA when a shaking device was used to pick red raspberries (Bell 1951). A few years later, because they were readily shaken from the plant, virtually all black raspberries were being harvested by machine. Black raspberry is thorny, small-fruited, lower yielding and grown for industrial use, so it was the first crop to suffer from a scarcity of pickers and rising costs (Clevenger 1964). Blackberries were next to be picked successfully and by about 1970 red raspberries, too, were being harvested by machines of various designs, all using the shake-and-catch principle (Booster and Bullock 1965, Crandall and George 1967, Ramsay 1974a, Martin and Lawrence 1976). Initially, harvesters were developed by growers reacting to economic and social pressures but later some critical comparisons were made between machine and hand picking (Hughes and Ricketson 1969) and design criteria for a machine were published (Nyborg and Coulthard 1969).

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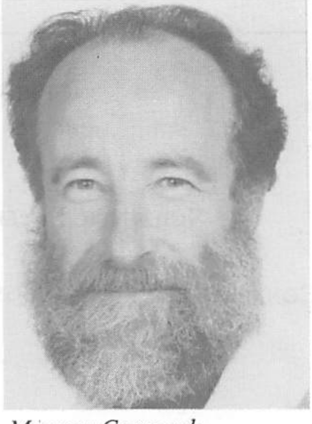
Brian Williamson



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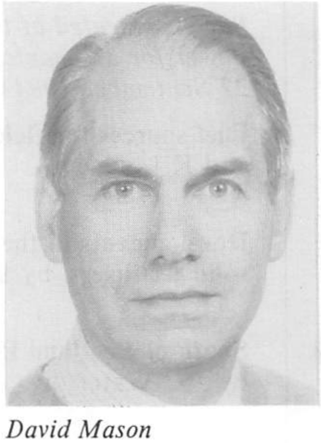

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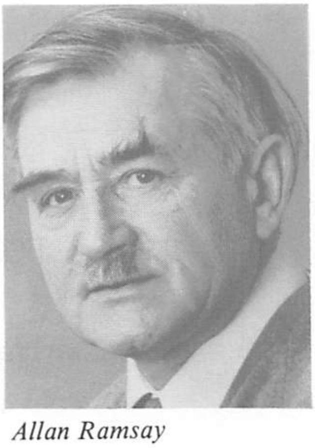


Allan Ramsay

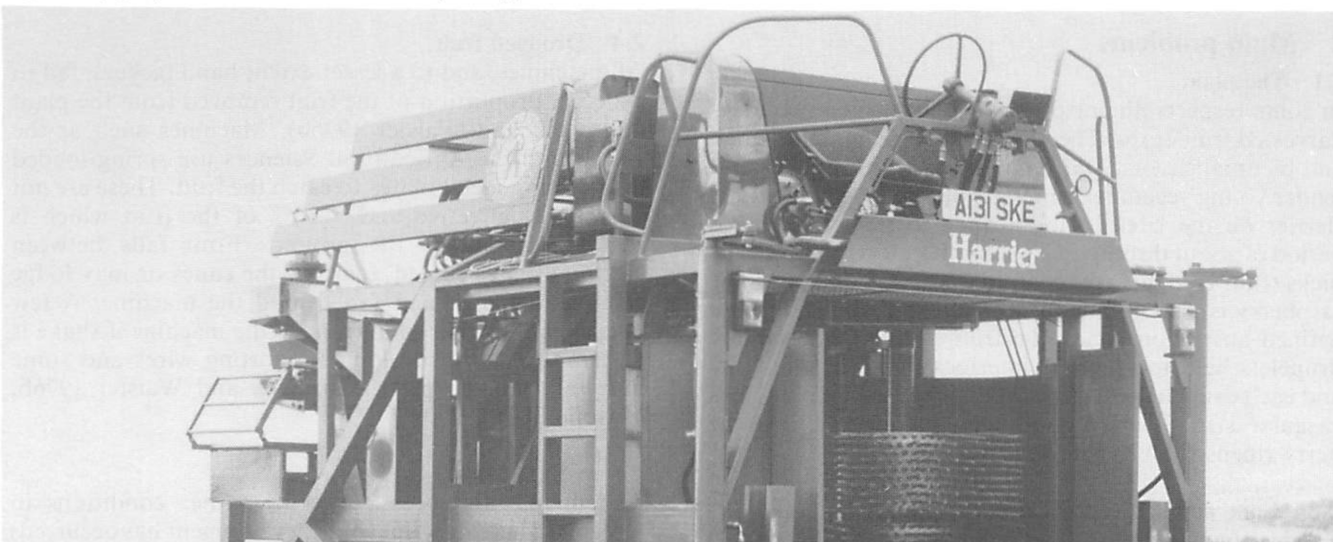
In Scotland, a shortage of pickers in the mid-1960s stimulated interest in machines to pick raspberries and a group of growers and research workers visited the USA in 1966 to examine the problems (Jennings *et al* 1966). The results of preliminary experiments conducted at the Scottish Horticultural Research Institute (SHRI), now the Scottish Crop Research Institute (SCRI), with a static shaker built by the Scottish Institute for Agricultural Engineering (SIAE) (Gilfillan 1971) were sufficiently encouraging for a tractor-drawn Agricultural Sciences machine (fig 1) to be imported in 1969 by the Scottish Institute of Agricultural Engineering to continue the project with the Scottish Crop Research Institute. Subsequently, a number of prototypes were tested, including one made by Barclay Ross and Hutchison of Aberdeen, one by PECO of New Zealand, one by Pattenden Engineering of Kent and three stages of development by Hally of Perthshire. A horizontal canopy harvester designed and built in New Zealand has been used at East Malling Research Station (Holloway 1984).

Fig 1 Trailed Agricultural Sciences harvester 1970

Two prototype machines (fig 2) have been built by Pattenden Engineering for commercial use in 1984/5.

The work which forms the basis for this paper was done with the Agricultural Sciences harvester, an experimental rig built and operated by the Scottish Institute of Agricultural Engineering (fig 3) and a Littau harvester imported from the USA and used by the Scottish Crop Research Institute (fig 4).

Fig 2 Self-propelled Pattenden 'Harrier' prototype harvester 1984



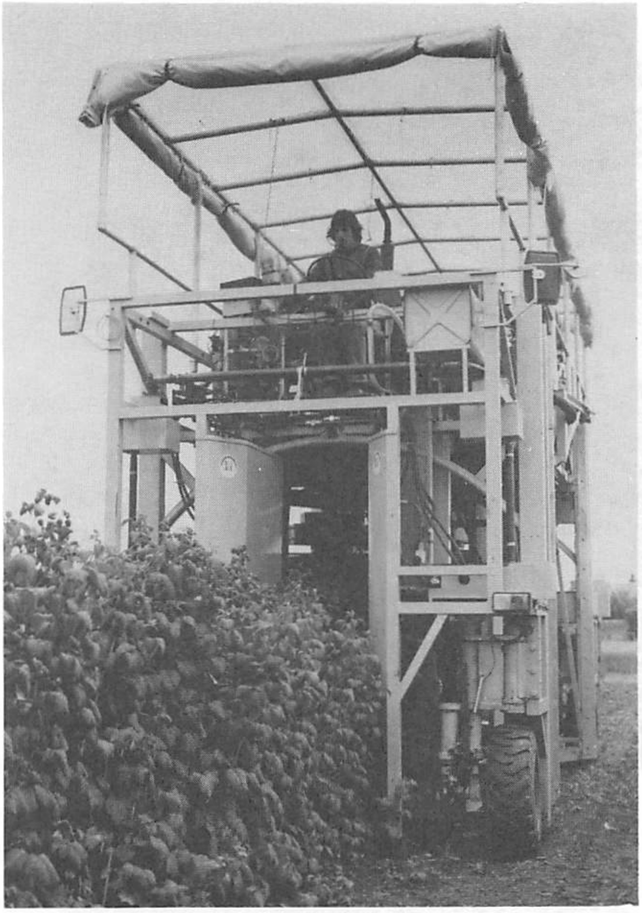


Fig 3 Self-propelled SIAE experimental harvesting rig 1980

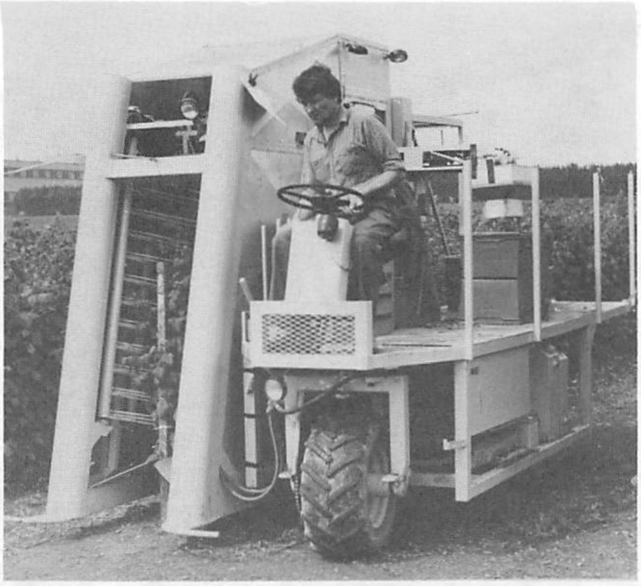


Fig 4 Self-propelled Littau harvester 1980

2 Main problems

2.1 The plant

In some respects, the raspberry is unlike other machine-harvested fruit crops. The plant has a perennial rootstock and biennial shoots, and both woody fruiting canes and tender young vegetative canes are present at picking time. Berries on the lateral shoots ripen in sequence over a period of about three to five weeks; therefore, a number of picks (four to eight) are required to harvest the crop. The raspberry is also unique in not having a single and well defined abscission zone. The fruit comprises about 100 drupelets held together by interlocking epidermal hairs and each drupelet is attached to the receptacle (plug) by a vascular strand which gradually distintegrates as the berry ripens (MacKenzie 1979).

2.2 Cane damage and disease

Yield reductions of up to 30% have been recorded in plantations harvested by machine in the previous year (Cormack and Waister 1976a). This loss was due mainly to infection of wounds (figures 5, 6) on young canes by the cane blight fungus *Leptosphaeria coniothyrium* which results in the death of individual laterals or of the entire cane (Williamson and Hargreaves 1976,1978, Hargreaves and Williamson 1978).

2.3 Fruit selection

Because of the ripening pattern of the raspberry crop and the physical structure of the plant, mechanical shaking results in some under-ripe fruit being removed. The proportion of green fruit picked may be minimised by correct machine adjustments (Cormack 1983, Ramsay 1983) but the complete elimination of green fruit would require such small shaking forces that very few ripe fruit would be picked. A compromise setting must therefore be used and this invariably results in a few green fruit being picked and some ripe fruit being left unpicked. By the next harvest this ripe fruit will have become over-ripe and may have developed grey mould (*Botrytis cinera*). In addition, a few ripe fruits complete with plug may be harvested because their pedicels fracture before they have separated from their receptacles and occasionally whole, or parts of, laterals with fruit are collected (Cormack and Waister 1976b).

2.4 Dropped fruit

All machines, and to a lesser extent hand pickers, fail to collect a proportion of the fruit removed from the plant (Cormack and Waister 1976b). Machines such as the Littau and the Agricultural Sciences use spring loaded overlapping metal plates to catch the fruit. These are not completely effective and 5–15% of the fruit which is removed drops to the ground. Fruit falls between catching plates forced apart by the canes or may lodge briefly in foliage and fall behind the machine. A few berries may also drop in front of the machine if shake is transmitted forward along supporting wires and some may fall between picks (Cormack and Waister 1976b, Mason 1982).

2.5 Climate

The main differences between weather conditions in Oregon (where most machine development has occurred) and Scotland is in rainfall (Waister 1974). In the dry Oregon conditions, berries remain firm and there is little or no grey mould and very few interruptions to picking because of the rain. In the normally wet Scottish season, (Waister and Cormack 1978) the converse tends to occur, although in the dry years of 1982 and 1983 excellent samples of fruit were picked by machine throughout the season.

3 Progress in plant manipulation

3.1 Culture

The presence of both fruiting and vegetative canes during harvesting and the need for several passes of the machine to harvest the crop have led to investigations into

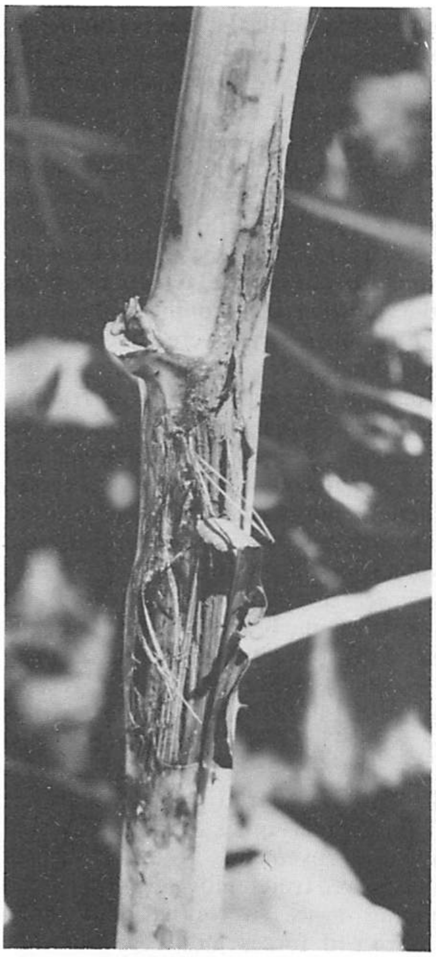


Fig 5 Young cane damaged by catching plates

Fig 6 Lateral development in spring following, (a) hand picking and, (b) harvesting by unmodified Agricultural Sciences machine

alternative growing systems to avoid damage to young canes. Physical separation of the young canes from the fruiting canes during harvesting was tried but serious disadvantages were recognised with all the annual

Fig 7 Separation of young and fruiting cane (biennial system) on left, fruiting canes; on right, vegetative canes

cropping systems. Rows where young canes were protected between two cordons of fruiting canes, as in the V-training system, were difficult to harvest as the fruiting laterals grew vertically inside the V and the released fruits could not be caught efficiently (Waister and Cormack 1972). The need to separate the young canes from the fruiting canes led to the development in New Zealand of the Lincoln canopy system and in Scotland of the biennial cropping system (fig 7).

The Lincoln system requires extraordinary cane vigour to provide the necessary dense canopy of horizontally trained fruiting canes. Moreover the wide spacing between the rows substantially reduces yield per unit area compared with the upright system (Thiele 1980, Rubens 1983). Consequently, the traditional upright training with support provided by posts and wires appears likely to be the most widely acceptable method of presenting the canes to the harvester.

In the biennial (or alternate-year) cropping system, the young canes are grown without competition from fruiting canes and, in the following year, the fruiting canes are grown without competition from vegetative canes. Half the plantation consists of vegetative canes only whilst the other half contains fruiting canes only, successive flushes of young canes having been killed by sprays of the desiccant herbicide dinoseb-in-oil. All fruiting canes are removed after harvest and, in the next season, these rows produce only vegetative canes which sustain no damage from the harvester. Without young canes in the fruiting rows, catching is improved because the catching devices can compress the canes more tightly. Because of improved ventilation a biennially cropped plantation dries more rapidly after rain than an annually cropped one and this probably reduces the risks of fruit diseases. Further opportunities for pest and disease control are possible because life cycles of insects and fungi would be interrupted and further mechanisation of cultural operations can be envisaged. Cultivars differ in their ability to produce high yields under biennial cropping (Waister and Cormack 198lb) and only those which produce yields between 150% and 180% higher than the yield from one season of annual cropping are likely to be cost effective (Turner 1980).

3.2 Breeding

Plant breeders have an important role to play in producing cultivars suitable for machine harvesting, but until recently there has been a lack of precise criteria by which they could select cultivars suitable for mechanical harvesting. All cultivars should have the commercially desirable qualities such as high yield, good quality and resistance to pests and diseases. In addition, a cultivar for mechanical harvesting should respond well to biennial cropping and have berries which are firm and cohesive and with plug attachments which weaken rapidly just before ripeness. Canes and lateral shoots should be thornless, the berries borne on laterals which are attached firmly to the canes, and the laterals and berry pedicels should possess sufficient flexibility to resist breakage (Jung, Bilanski and Evans 1974, Jennings 1974). A number of cultivars with varying combinations of these desirable characteristics have been identified at the Scottish Crop Research Institute.

4 Progress in machine design

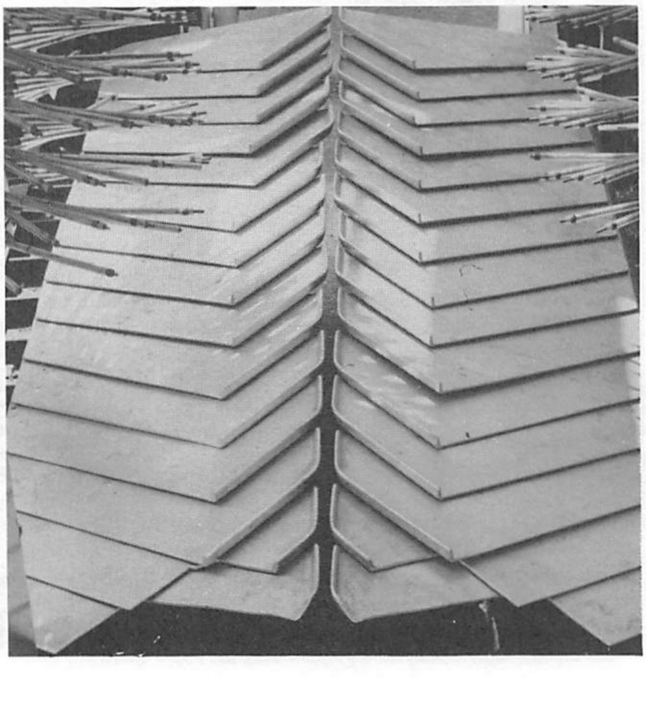
4.1 Picking devices

In common with other machines (such as the Weygandt), the shake imparted by the Agricultural Sciences machine is produced by free wheeling vertical cylinders furnished with a multitude of horizontal fingers which are rapidly reciprocated in a horizontal plane. Shake is imparted in other machines such as the BEI and Littau by trailing nylon rods reciprocated horizontally (Booster and Bullock 1965, Ramsay 1974a, Waister 1980, Waister and Cormack 1981a). Damage to canes and ripe or ripening berries should be avoided so that neither the current nor the following year's crop are reduced by damage from the shaking device or subsequent disease. To reduce damage to young canes by the vibrating fingers of the Agricultural Sciences machine, soft rubber covers were fitted over the metal fingers, so spreading the impact load over a larger area without diminishing the shaking of the fruiting laterals. Wounds were then rare in the upper part of the canes and infection by the fungus *L coniothyrium* was negligible in a year when conditions were otherwise favourable for infection; the plastic rods of the Littau harvester also caused little cane wounding or infection in the same trials (Williamson and Ramsay 1981).

Existing shaking devices rely on inertial 'snatching' and centrifugal force to separate the berry from its receptacle. The forces required to do this with a single or very few such inertial changes are so great that all berries receive relatively severe loadings. In consequence, unripe berries are removed when pedicels break, or ripe and unripe berries are removed in clusters when laterals are broken. The removal of 80–90% of the fruit at peak quality ie suitable for IQF (individual quick freezing), would require considerable improvements in the design of existing machines. Improved fruit removal was first noted when different shaking devices were used with model berries designed to record forces induced within the fruiting zone. A more selective technique for removing only ripe fruit was conceived by using centrifugal force in a way different from that normally employed in existing shaking devices and by taking advantage of biological changes occurring within the fruit.

Research at the Scottish Institute of Agricultural Engineering using accelerometers (Smith and Ramsay 1983) suggests that when the forces required to remove ripe fruit are used in a series of short duration shock loads rather than the normal inertial snatching type loading,

Fig 8(a) Damaging catching device



ripe fruit can be removed without pedicel breakage. The force applied to the berries must be maintained within narrow limits so that all receive the optimum shake. Forces below 0.5 N seem largely ineffective and those above 3 N damage the fruit and canes; the duration of each shock force should be *c* 0.002 s. To achieve worthwhile harvesting rates a large number of these shocks *c* 80 s^{-1} are required. Significant advances not only in improved selectivity but also in reduced damage and increased harvesting speed now seem feasible through engineering design.

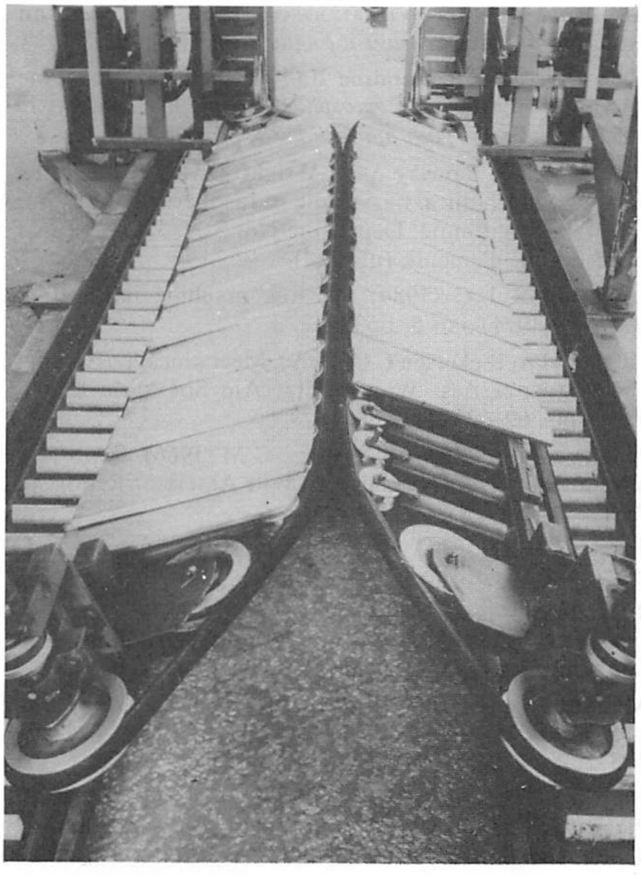
4.2 Catching devices

Attempts to reduce young cane damage by decreasing catching plate spring tension were unsuccessful and resulted in increased fruit spillage.

Damage by catcher plates (fig 8a) has been eliminated by the introduction of a patented SIAE fruit catcher (Ramsay 1981) (fig 8b). It consists of a pair of soft rubber belts which are positioned on either side of the row. Because they are driven backwards at the same speed as the harvester advances through the crop they remain stationary in their contact with the canes; sloped metal panels positioned above the idler pulleys tensioning the belts feed the berries to conveyors. This device minimised cane damage and its success in reducing disease was established by inoculating the belt marks on young canes with the fungus *L coniothyrium*. Infection was negligible and similar to that in unwounded canes similarly inoculated (Williamson and Ramsay 1984).

Avoidance of cane blight by improved machine design is important because it allows harvesting without a fungicide spray programme to protect the young canes and the attendant risks of strains of the fungus arising

Fig 8(b) Non-damaging catching device



tolerant to some fungicides. Nevertheless, the systemic fungicide benomyl, applied pre- and post-harvest has reduced the incidence and severity of vascular lesions at catching plate wounds and brought yields in the year after harvesting close to those from hand picked plots (Williamson and Ramsay 1981).

4.3 Cleaning devices

Mechanically harvested fruit can contain a wide range of extraneous material. A suction-type fan and ducting gives the best results with material which is lighter than the fruit but, provided the rubbish does not return to contaminate the harvested samples, properly designed blowing fan systems can be just as effective. Leaf stalks which generally become detached from the leaf blades towards the end of the harvest period and other contaminants which are heavier than the berries and cannot be separated by an air blast can be removed by slotted sections of belt or disc type cleaning spools. A final cleaning operation may be necessary by hand from a conveyor belt.

4.4 Grading devices

The possibility of a fruit grading device mounted on the harvester warrants further attention as it would enable the grower to supply fruit of different qualities to suit various market requirements. Devices ranging from relatively simple belts for manual separation of different fruit qualities to highly sensitive colour sorting equipment could be used. A simple grading device which separates whole firm berries from soft or broken berries has been investigated and shows promise (Ramsay 1974b).

5 Progress of machine use

5.1 Adjustment

Optimal performance of any harvester depends primarily on the control of three variables, finger vibration frequency, length of stroke and forward speed.

Finger vibration frequency is probably the easiest variable to adjust accurately. Attempts to improve performance of the Agricultural Sciences machine by increasing the severity of shaking resulted in the removal of a higher proportion of the ripe fruit but the proportion of the 'green' and 'ripe-with-stalk-attached' berries removed was even greater (Mason 1985). This resulted in an increase in percentage of green and ripe-with-stalk-attached berries in the harvested samples (Cormack 1983, Ramsay 1983). The optimum frequency of the Agricultural Sciences machine appears to lie between 6.6 and 10 Hz and that of the Littau between 2.7 and 4.0 Hz.

Increasing the length of stroke of the fingers increased the amount of ripe fruit removed, but also disproportionately increased the amount of green fruit removed (Ramsay 1983).

Forward speed is also important because the higher the speed, the greater the area which can be covered by one machine. Increasing the speed of the Agricultural Sciences harvester reduced the percentage of the crop harvested, unless there was an increase in the vibration frequency of the shaking device (Ramsay 1983). However, with the Littau machine, increasing the forward speed increased the quantity of fruit removed but, as the amount of fruit dropped to the ground also increased, the weight of ripe fruit collected was similar to all speeds (Cormack 1983). Speeds of 2–3 km/h appear to be necessary to make machine harvesting an economic proposition.

5.2 Harvest scheduling

The first hand pick from a raspberry plantation is usually taken when about 10% of the crop is ripe and fruit is thereafter picked at intervals of three to seven days. Early work with the Agricultural Sciences harvester showed that if the first machine pick took place at the same time as the first hand pick, excessive quantities of green berries were removed and yield was reduced (Ramsay 1983). Subsequently, a mathematical model of fruit development and harvesting showed that the most efficient option was to delay the first harvest until about 30% of the potential crop had ripened and then pick at two day intervals (Topham and Mason 1976, 1981). This was confirmed in later field trials. However, recent research at the Scottish Institute of Agricultural Engineering has shown that a fruit removal device with greater sensitivity can be devised (Smith and Ramsay 1983). Such a device should permit earlier machine picking without removing many of the green berries and produce a sample of fruit superior in quality to that harvested by present day machines.

5.3 Economics

While pickers are available in adequate numbers and at relatively low costs, a machine harvesting system is unlikely to appeal to growers (Wright 1974). Alternatively, if pickers became scarce or too expensive, growers would be obliged to consider machines to harvest their crops. In such situations, machine harvesting could not be compared with hand picking but it would have to be judged on the profitability of the whole enterprise. The cost of a machine, the area it can cover (forward speed), and the quantity and quality of harvested fruit would be the main considerations. These have been assessed both for the Littau harvester and the SIAE experimental rig (Haughey *et al* 1982). At present, the only machine in quantity production (Littau) is likely to cost about £35,000 in the UK; the new Pattenden machine is about £44,000. The Littau harvester travels at about 1.6 km/h (0.25 ha/h); the optimum speed of the Pattenden prototype harvester has yet to be determined but the machine is expected to harvest 0.4 ha/h.

6 Conclusions

Experience has shown that existing machines can remove about 70% of the ripe fruit that would be harvested by competent hand pickers and that samples are contaminated by varying quantities of green and ripe-fruit-with-stalk attached, broken fruit and mouldy fruit; plant and insect contaminants may also be present.

Machines fail to catch all the fruit removed from the plant and can damage young canes and reduce subsequent yields. Nevertheless, in favourable weather conditions and with a cultivar suited to machine harvesting, a high proportion of the ripe fruit picked by machine is of top quality and contaminants can be easily removed.

Some problems, notably those associated with the selection of ripe fruit, remain but the prospects of solving them are good. Improvements in shaking and catching devices will improve discrimination and minimise damage to young canes, and plant breeders will develop cultivars with the characteristics required. The adoption of cultural systems such as biennial cropping will eliminate damage to young canes, allow many cultural operations to be mechanised and simplify management of the crop.

A viable mechanical harvesting system is available to raspberry growers now and a number of improvements are likely in the near future. It is hoped that the advances made in improved fruit selectivity and in the reduction of damage, will be built into new machines like the Pattenden 'Harrier' harvester now the subject of a co-operative project between Pattenden Engineering Limited and the Scottish Institute of Agricultural Engineering, with assistance in performance evaluation from the Scottish Crop Research Institute, East of Scotland College of Agriculture and growers. Successful incorporation of these improvements would permit existing cultivars to be mechanically harvested on an annual system with harvesting costs about the same as those of present day hand harvesting.

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Thermal conductivities of some West African fibres

E A Baryeh

Summary

THE replacement of imported insulating materials with local ones, in crop drying, refrigeration and solar energy equipment, is important for developing African countries because of the savings both in cost and in foreign exchange.

Modifications were made to a standard apparatus used for the determination of the thermal conductivities of poor conductors. The modified equipment was used to assess the thermal conductivities of two fibres from plantain and coir. The resulting thermal conductivities provide indices for assessing the suitability of the fibres as insulating materials.

The conductivities of the plantain stem fibre were found to vary from 0.038 to 0.12 W m^{-1}°C^{-1}, those of the plantain fruit stalk fibre from 0.046 to 0.14 W m^{-1}°C^{-1} and those of coir from 0.029 to 0.11 W m^{-1}°C^{-1} with the change in the fibre packing density from 10 to 350 kg/m^3.

Introduction

Materials having high resistance to heat transmission are used as protective insulation in crop drying, refrigeration and solar energy equipment. The effectiveness of thermal insulation is measured by the thermal conductivity or quantity of heat which passes through unit thickness of a material per unit time when a temperature difference of 1°C is maintained across its thickness.

The annual loss of grain after harvest (even in a developed country like the USA) is estimated at ten per cent and of hay at 28% of production (Hall 1980). The loss of fruit and vegetables is estimated at 35 to 40% of production (Hall 1980). These losses are much higher in developing countries which usually do not have enough drying, storage and refrigeration facilities. A greater part of these losses in developing countries result from ineffective drying, aeration and refrigeration, even where these exist. In crop drying and aeration processes, excess moisture is extracted by applying heated air to the crop. The use of insulating materials in certain strategic parts of the crop drying equipment improves the drying and storage processes by reducing some of the crop losses (Baryeh 1972).

Solar water heating is another process in which insulating materials are used. Insulation is put on the collectors, parts of the piping system and the storage tank to reduce the heat losses from the system to its surroundings.

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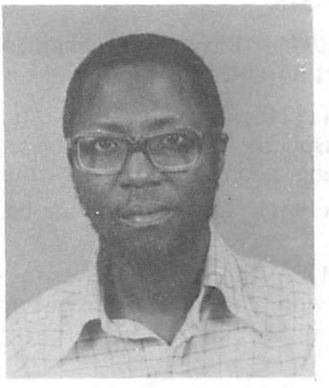


Crop storage by chilling or refrigeration also involves the use of insulation materials. Metal bins in the storage units are usually insulated with a layer of cork or other suitable material to prevent heat loss from the unit to the surroundings.

All these insulated systems usually contain imported insulating materials which have known thermal properties, but which are expensive and require foreign exchange. Local materials are cheaper and more convenient but the thermal conductivities have not been established. The purpose of this study was therefore to establish the conductivities of the local fibres and the suitability of the fibres for insulation. The equipment used in this study is a modified version of that used for finding the conductivities of poor conductors.

Literature review

Equipment is available for determining the thermal conductivities of metal rods and poor conducting materials in the form of thin circular plates (Nelkon 1970). There is also equipment for measuring the conductivities of tubular materials (Rogers and Mayhew 1965). Ohuonu and Karima (1982) modified the equipment used for tubular materials to determine the conductivities of some building materials. Equipment for determining the conductivities of fibrous, porous materials is generally not readily available.

Heat loss resulting from the absence of insulation material on small batch-in-bin driers can be as high as 20 to 25% of the available heat for drying (Baryeh 1972). In one investigation, it was found that the absence of fibre glass insulation on the metal fan housing and duct of a batch-in-bin drier increased the drying time of 1.5 m^3 of maize from 20 to 14% moisture content (wb) by eight hours (Baryeh 1972). Some investigators, having realised the extent of these losses, have utilised insulation materials ı their work. Ali and Sakr (1981) used insulation material in the construction of a solar vegetable drier in Egypt. Bassey (1981) included some insulation material in a grain drier in Sierra Leone. Ezeike (1981, 1982) utilised insulation in three types of solar drier. These investigators have not, however, specified the type of insulation materials they used. The Volunteers in Technical Assistance (1980) have recommended wood wool, dried grass, dried leaves and coir as insulation in two solar grain driers but have published no figures to support the recommendation.

Experimental procedure

The equipment used in this investigation is shown schematically in fig 1. The major components are an aluminium steam chest and slab with thermometers and paper tape, a steam supply unit and a clamping device. The chest and slab have equal diameters and, being of the same material and with the same level of neatness, they exhibited the same emissive power. Nelkon (1970) discussed the use of this equipment (without the paper tape and clamping device) for determining the thermal conductivities of poor solid conductors in the form of thin circular plates. The paper tape which was manufactured from sugarcane bagasse and clamping device were added in this study to enable the equipment to handle fibres. The steam chest was a hollow cylinder with a base thick enough to carry a thermometer.

To establish the accuracy and effectiveness of the equipment, it was used first to find the conductivities of asbestos sheet, fibre glass and mahogany and calibrated with reference to the values listed for these materials by Brady (1972), Perry (1976) and Weast (1976), respectively (table 1). Weast (1976) gives the thermal conductivity of mahogany as 0.13 W m $^{-1}$°C $^{-1}$.

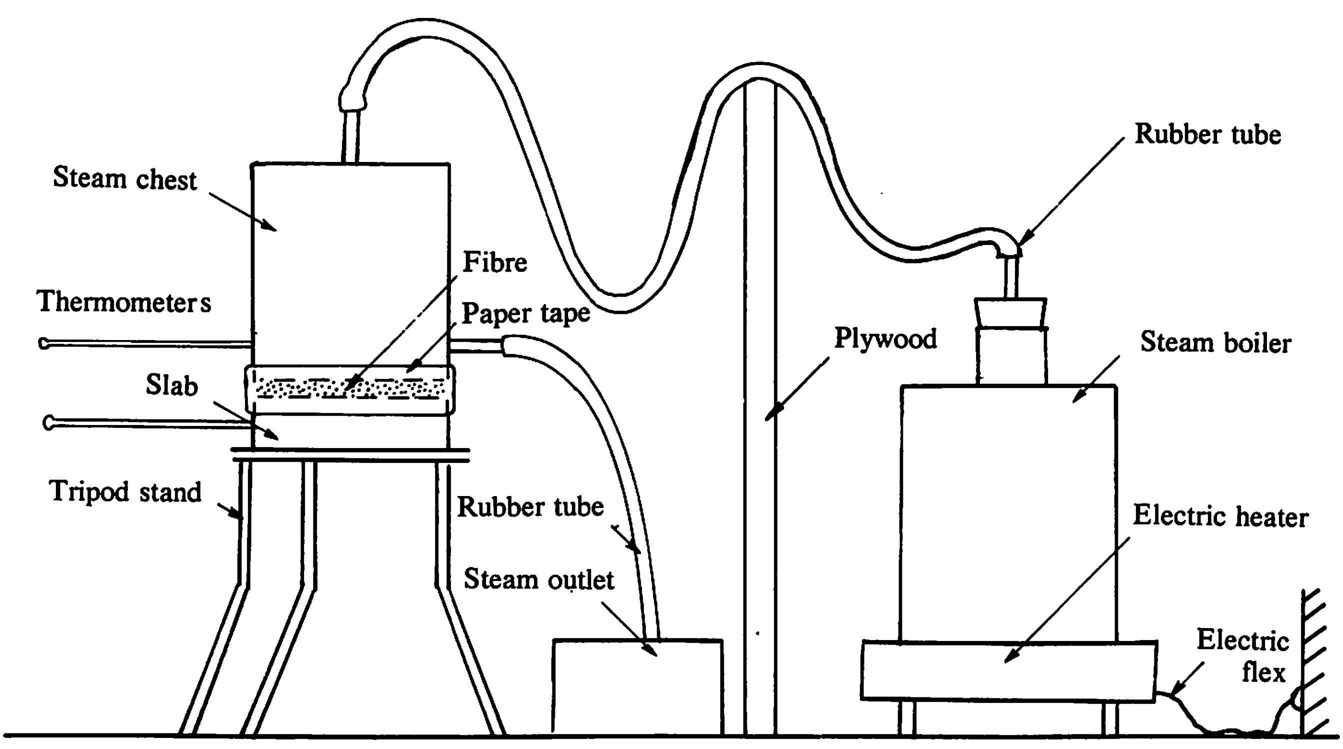
The fibre under investigation was carefully woven into a thin circular form or evenly and carefully spread into a thin circular form (fig 2). As the thermal conductivity of porous insulation may be increased if water is absorbed into the spaces within it (Brady 1972), the fibres were kept dry by holding them in a chamber which was aerated from time to time. The slab was placed on a level tripod stand with paper insulation between the stand and the slab. The fibre under investigation was placed on the slab, with the chest above. Vaseline was used to improve the thermal contact between the fibre and the chest and slab. The fibre edges were trimmed to the slab and chest diameter and the paper tape was wrapped round the fibre edges as indicated in fig 1. The tape which is a modification to the existing equipment prevented heat and air leakage from the fibre. The equipment was mounted in a draught free wooden pannelled room to ensure that the air temperature around the equipment was reasonably uniform and constant, consequently preventing varying heat loss from the slab. The temperature around the equipment was monitored to make sure it was reasonably uniform and constant. A wooden board placed between the boiler and the chest-fibre-slab assembly (see fig 1) prevented direct heat transfer from the boiler unit to the chest-fibre-slab unit. The assembly was left undisturbed, with steam passing freely through the chest, until steady state was achieved in 45 to 100 minutes. The readings on the thermometers were noted, the thermometers being interchanged and again read when steady state was achieved. The mean slab temperatures and chest temperatures were noted. Interchanging the thermometers and averaging their readings nullifies inherent errors that may be associated with any of them.

Table 1: Thermal conductivities of some imported insulation materials

Material	*Density, kg/m³*	*Thermal conductivity, (W m $^{-1}$°C $^{-1}$)*
Asbestos sheet	—	0.042 **
Asbestos wool	392.39	0.100 *
Cork (ground)	125.56	0.045 ** ++
Cork board	94.17/166.37	0.037/0.043 ++
Fibre glass wool	47.09	0.039 +
Glass wool	62.78	0.042 ++
Kaolin wool	156.95	0.102 *

* *Baumeister;* ** *Brady;* + *Perry;* ++ *Weast.*

Fig 1 Experimental apparatus



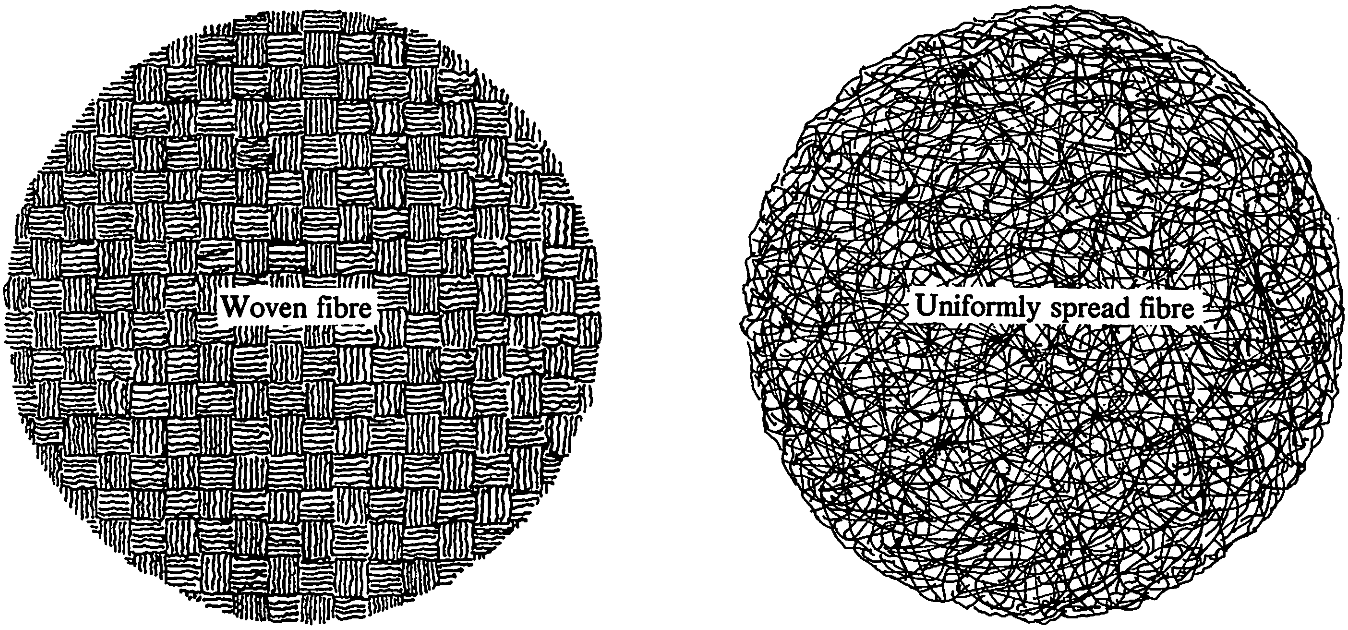


Fig 2 Sketch of woven and uniformly spread fibres

The fibre was then removed. The chest was kept on the slab to raise the slab temperature by about 10°C. The steam chest was removed and the fibre was placed on the slab with the paper tape in place. Alternatively, the steam chest may be removed, leaving the fibre and paper tape in place. The slab is then warmed with a low bunsen flame until its temperature is about 10°C above the steady state temperature reached. In either case, the temperature on the slab thermometer was noted at convenient time intervals. These readings were plotted to form the cooling curve shown in fig 3. The fibre was left on the slab to prevent heat loss and to facilitate in assessing the rate at which the slab temperature changes at the steady temperature. Putting other insulation in place of the fibre for this part of the investigation serves the same purpose. In particular, cork board and asbestos sheet were found to be as effective as the fibre. The slab was then weighed.

The height of the slab and chest was measured with and without the fibre in place using vernier calipers. The fibre thickness was obtained by subtracting the two readings. The fibre was weighed on a sensitive scale and its diameter was measured with a scale rule. The volume, V, of the fibre (including the pores) was calculated as:

$$V = \pi d^2 t/4 \tag{1}$$

where: d = diameter of fibre;
t = thickness of fibre.

The packing density, D, of the fibre was then calculated as:

$$D = m/V \tag{2}$$

where: m = mass of fibre.

The clamping device, another modification to the existing equipment, was used where the fibre density exceeded 100 kg/m^3. In these cases, the fibres were compressed by clamping the steam chest, fibre and slab assembly together to obtain the required density. The clamping was necessary to establish the density which yielded the minimum thermal conductivity and the trend of the conductivity variation.

The above procedure was repeated for the same fibre densities and for the three fibres under consideration.

If the steady state temperatures of the chest and slab are T_2 and T_1, respectively, then the rate at which heat, H_1, passes from the chest through the fibre to the slab at steady state is given by:

$$H_1 = KA(T_2 - T_1)/t \tag{3}$$

where: K = thermal conductivity of the fibre;
A = cross-sectional area of the fibre.

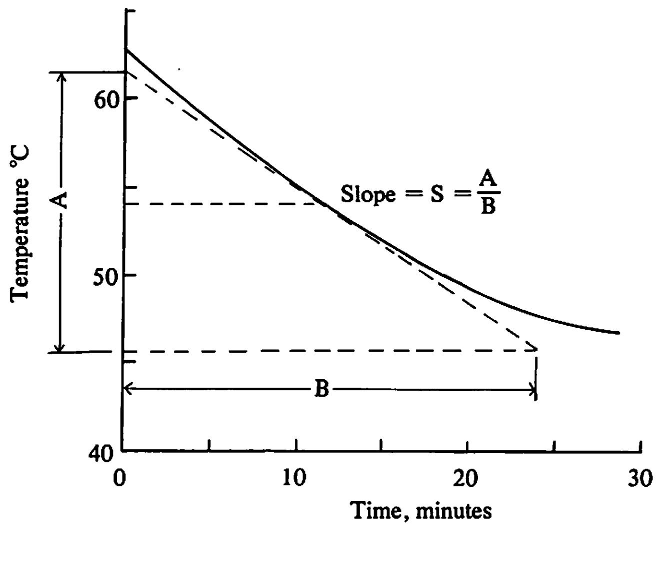
The slope(s) of the cooling curve at temperature, T_1, (fig 3) is proportional to the rate at which the slab loses heat at temperature, T_1. The rate at which the slab loses heat, H_2, at temperature, T_1, is given by:

$$H_2 = Mcs \tag{4}$$

where: M = mass of the slab;
c = specific heat capacity of the slab.

When steady state is attained, the rate at which heat is

Fig 3 Cooling curve for fibre



conducted across the fibre is equal to the rate at which it is emitted from the exposed surfaces of the slab:

$$K = \frac{Mcst}{A(T_2 - T_1)} \tag{5}$$

It may be noted that, according to Newton's law of cooling, the rate of loss of heat is proportional to the excess temperature of a body over that of its surroundings. Therefore, equation 5 may be written as:

$$KA\,(T_2 - T_1)/t = \text{Constant}\,(T_1 - T_0)$$

where: T_0 = ambient air temperature.

Hence, for a specimen of another material of thermal conductivity, K', and thickness, t', with steady state temperatures, T'_2 and T'_1, a comparison of the thermal conductivities of the two specimens can be obtained without the necessity of proceeding with the cooling curve part of the experiment. In such a case, K' can be evaluated from the relation:

$$\frac{K'}{K} = \frac{t'(T'_1 - T_0)\,(T_2 - T_1)}{t(T_1 - T_0)\,(T'_2 - T'_1)} \tag{6}$$

Results

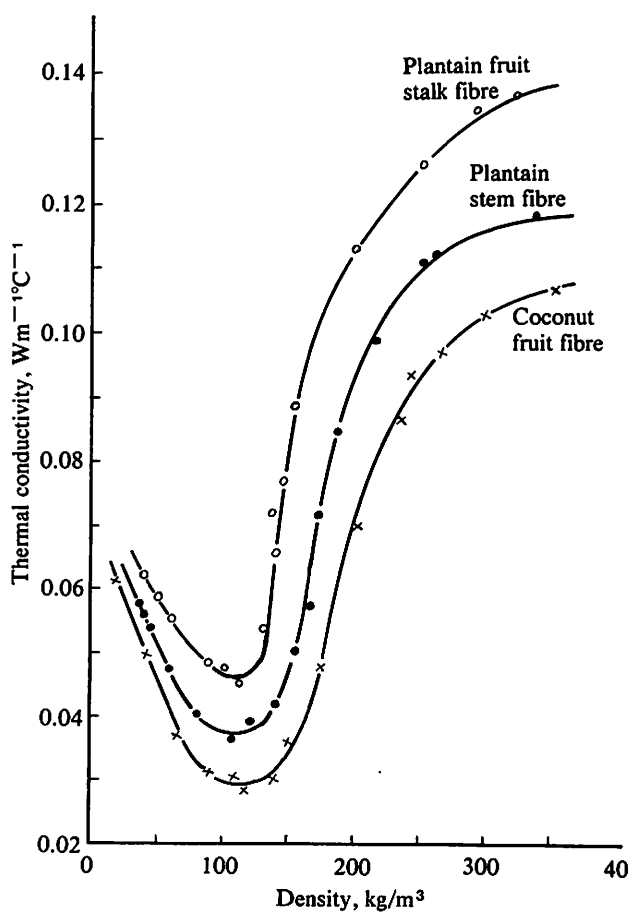
Equation 5 was used to calculate the thermal conductivity values for various fibre densities, using the specific heat capacity of the slab of 0.9211 KJ $kg^{-1}°C^{-1}$ which is listed by Weast (1976) for the aluminium material used for his slab. The variation of the thermal conductivities with the fibre densities for the three fibres investigated is shown in fig 4. There was no difference in the thermal conductivities between the woven fibres and the evenly spread fibres. The thermal conductivities for all the fibres decreased with increasing density of packing to some minimum value and then increased with subsequent increase in density. After a certain point, the thermal conductivity approached a constant value as the air pores became more and more depleted. This conforms with the statement that the efficiencies of fibrous insulation is partly due to their air spaces (Brady 1972). For all the fibres, the thermal conductivities reached a minimum when the density of packing was 120 kg/m^3. The minimum thermal conductivity obtained for the plantain fruit stalk fibre, the plantain stem fibre and coir were 0.046, 0.038 and 0.029 $W\,m^{-1}°C^{-1}$, respectively. At a packing density of 340 kg/m^3, the plantain stem fibre and the coconut fruit fibre or coir were quite close to their maximum thermal conductivity values which were not achieved because the equipment did not create densities higher than 340 kg/m^3. This is just as well since such high densities yield undesirably high thermal conductivity values for insulation work.

The results obtained are influenced by the amount of air in the fibre or its porosity. At low fibre densities, the volume of air within the fibre is comparatively high. This encourages heat transfer by convection of the air within the fibre. The air near the steam chest gets hotter than that near the slab, resulting in convection currents being set up within the fibre. Heat transfer by radiation is also higher at lower fibre densities due to the relatively high volume of air within the fibre. The result of these increased heat transfers at low fibre densities is an increase in the temperature, T_1, resulting in a decrease in the temperature difference, $(T_2 - T_1)$, which in turn gives a high thermal conductivity value (see equation 5). As the air volume within the fibre decreases, convection and radiation are almost eliminated. Since air is itself a poor conductor of heat, it helps the fibre to achieve a composite low thermal conductivity value when the conduction and radiation effects are reduced. Consequently, the thermal conductivity decreases as the density increases until a minimum thermal conductivity value is attained. With further reduction of the air volume within the fibre, it becomes something like compacted sawdust. At this stage, heat is transferred from the chest to the slab, mainly by conduction through the fibre itself. The effect of the air within the fibre is thus greatly minimised or almost eliminated, diminishing the bad conduction effect of the air. The thermal conductivity value then approaches the thermal conductivity of the fibre without air, resulting in increasing thermal conductivity values, as shown in fig 4. Sawdust, for example, has a lower thermal conductivity than wood because of the tiny air pores within it.

Coir had the lowest thermal conductivity values (fig 4). The lower the thermal conductivity of an insulation material, the better it is for insulation work. Hence, coir is the best insulator of the three, followed by plantain stem fibre and plantain fruit stalk fibre, respectively.

Table 1 gives the thermal conductivities of some commonly imported insulation materials (Baumeister 1967, Brady 1972, Perry 1976, Weast 1976) for comparison purposes. Comparing the thermal

Fig 4 Fibre thermal conductivity versus density of packing



conductivity values of the fibres in this study with those in table 1, it is seen that the local fibres are as good as the imported materials for insulation applications. If the fibre density is correctly selected, comparison shows that the local fibres could even be more effective than some of the imported insulation materials.

The curves in fig 4 can be used to determine the weight of insulation material required for a given space to obtain a certain quality and effect of insulation. This process eliminates the problem of using more or less insulation material than is necessary. If very effective insulation is needed, the fibre density that yields the lowest thermal conductivity value should be used. For example, in a solar collector with a 1 m by 1 m base, 1.15 kg of plantain stem fibre per centimetre of depth are required to achieve an effective insulation based on the minimum thermal conductivity value.

From equation 5, taking logs and differentiating, the percent error in the thermal conductivity is given by (Nelkon and Ogborn 1966):

$$\delta K(100)/K = [\delta M/M + \delta s/s + \delta t/t + 2\delta d/d + 2\delta T/(T_2 - T_1)]100$$

assuming equal errors in the thermometer readings. The percentage errors in M and d are 0.07 and 0.25, respectively. The average percentage errors in the measurements of s, t and $(T_2 - T_1)$ are 0.15, 0.1 and 0.5, respectively. Thus, the mean error in the thermal conductivity is given by:

$$\begin{aligned} K \text{ error} &= 0.07 + 0.15 + 0.10 + 0.5 + 1.0 \\ &= 2 \text{ approx} \end{aligned}$$

The errors in s, t and $(T_2 - T_1)$ depend on the values of the quantities themselves, unlike M and d whose errors vary according to the fibre specimen size and density. Taking this into account, the percentage error in the thermal conductivity varies from 1.5 to 3.0%. Similar analysis indicates that the error in the fibre density is 0.6%.

Conclusion

For any given power consumption, insulation is advantageous in crop drying, crop refrigeration and solar energy utilisation because it permits higher temperatures to be achieved in drying and solar work and lower temperatures to be achieved in refrigeration work. Alternatively, it permits the same temperature to be achieved by a smaller plant at a lower capital cost or with the same refrigerating plant at a lower power cost. In this investigation, the thermal conductivities of three West African fibres were evaluated to provide indices of their effectiveness and suitability as insulation materials. Comparison of the thermal conductivity values of these fibres with those of asbestos, cork, fibre glass, glass wool and kaolin wool indicates that the fibres tested in this study will be as effective as imported insulation materials and even more effective if the fibre density is correctly selected. Since these fibres are locally available, they will be convenient and cheap for West Africans and should eliminate the need to spend foreign exchange for imported insulation materials.

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Metal finishing processes

N A Tope

Summary

THE metal finishing industry is in a constant state of development and change in an effort to reduce its manufacturing costs, to produce higher grade coatings, and to meet the cosmetic demands of sales policy.

The paper will briefly attempt to survey the current state of those processes of interest to agricultural engineers, and attempt to predict cost advantageous developments for the future.

Introduction

WITH ever increasing size, sophistication and cost, purchasers of agricultural equipment will inevitably insist upon improved protection against deterioration through corrosion. Although having a high asset value, the equipment may well be only used occasionally and is generally stored in outbuildings, if not in the open. The plant needs to be protected so that it is always available for immediate use and it desirably retains an attractive appearance to ensure a good second-hand value.

An additional hazard is the modern use of corrosive chemicals, such as herbicides and fertilisers. Even though not actually required to handle these materials, other prime plant is frequently affected by wind blown spray.

Protective metal finishing processes have their origins in the earliest times, but are still in a process of evolution and improvement. This paper will attempt to draw attention to some options currently available or likely to be so in the near future.

In the author's view, cost effectiveness should not be exclusively considered as a matter of cost reduction, but rather as providing better value for money.

Electroplating processes

Although initially developed early in the nineteenth century, electroplating, the mainstay of the metal finishing industry, found little real engineering scope until the 1914/18 war. From this time, until very recently, both electroplating processes and plant have been the subject of intensive technical development, mostly to satisfy the volume needs of the motor car industry.

Although new developments and progress will undoubtedly be made, it should not be anticipated that significant cost cutting changes to the basic processes are likely in the foreseeable future. More progress is probable through improvements to the pre and post-plate treatments. These are proving to be most beneficial by improving the quality and effectiveness of the plating processes.

Substrate quality

It is now being increasingly recognised that the metallurgical quality of the substrate has a dominant effect upon the quality of the coating and this feature is being utilised to produce coatings of greater durability and quality. Some of the more recently developed processes are entirely dependent upon the controlled quality of the substrate. For example, it has been found feasible to reduce the thickness of hard chromium coatings on many products by specifying better quality steels and by machining in such a fashion as not to leave the substrate in a distorted or stressed condition.

Most electroplate coatings are intentionally quite thin, but even so it is increasingly appreciated that some coatings may have to be applied rather thicker than is fundamentally necessary so that the coating may fill in surface undulations or neutralise the effect of a stressed substrate.

Many house specifications now demand low temperature pre and/or post-plate thermal stress relieving treatments, as this has been found to be very beneficial in reducing hydrogen embrittlement, fatigue failure, and enhancing the quality of the plating processes.

Passivation treatments

Just prior to the 1939/45 war, it was noted that the corrosion resistance of zinc surfaces could be substantially improved by dipping the parts in an inexpensive buffered dilute chromate solution, and this has led to the almost universal use of this kind of treatment for zinc and cadmium coatings. Although the early treatments only produced yellow to khaki coloured coatings, the formulations have since been modified to produce passivation processes which are more lustrous and blue (simulated chrome plate), black, drab olive (for military applications) and through a dyeing procedure, many other colours of value cosmetically or for identification purposes.

The concept too has been applied with beneficial results to other metals such as tin and aluminium. For special purposes the coatings may be impregnated with water based lacquers or Poly Tetra Fluoro Ethylene (PTFE) resins.

It is worth noting that the recent fears as to the toxicity of cadmium plate have now largely been dispelled, although it is likely that future limits on cadmium effluent discharges may be more rigorous. It is generally accepted that cadmium plate is a most cost effective treatment for the protection of steel substrates and components subject to marine or saline environments, but that the lower cost zinc coatings are at least as effective for protection against land based environments.

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These twin metals are currently the standard protective coating for fasteners, hose couplings and other similar small precision parts.

For many years, there has been a technical challenge to produce a successful commercial process for the deposition of aluminium, since in theory this metal should be equally effective as cadmium and zinc for the protection of steel. It is also available in unlimited quantities, and so far is not regarded as a toxic hazard. Several alternative processes are now available but industry has not yet been able to make up its mind about their adoption. Although aluminium is such a cheap metal, the plant to apply it is still very expensive on account of the sophisticated technology involved.

Undoubtedly, the most significant post-war development in metal finishing has been the evolution of the duplex nickel-micro-cracked chromium plating processes. These have so enhanced the durability of bright nickel-chromium plated items as to enable motor car manufacturers to confidently increase their warranty guarantee from six months to five years, and this concept of duplex micro-cracked plating is now being increasingly applied with benefit to engineering coatings, eg Duplex Hard Chromium process and Ni-Cad (cadmium coatings over electroless nickel and then thermally diffused).

Pure corrosion resisting lead coatings are easily and cheaply applied by electro-deposition and in many instances could constitute a cost effective substitute for stainless steel in the manufacture of spray jets, valves, sensors, battery containers, etc. Lead plating has long been a principal protective treatment in Germany for railway rolling stock.

Process plant

The modern approach to process transfer plants is through what is now frequently referred to as the Glydo, or cantilever beam, principle. In this type of plant, either lightweight structures or cantilever beams operated from the side are speedily moved with great precision over the top of the process tank line so that the flight bars from which the plating jigs are suspended are lifted and lowered and moved forwards and backwards with elegant precision. Linear or stop electric motors are now usually preferred to hydraulics. The movements are controlled through modern electronics and programmer systems to a degree where it is now feasible to individually program each flight bar on the plant to provide an infinite combination of processing program and times. In addition, a number of quite separate sub-plating units may be integrated to further enhance the versatility of the facility.

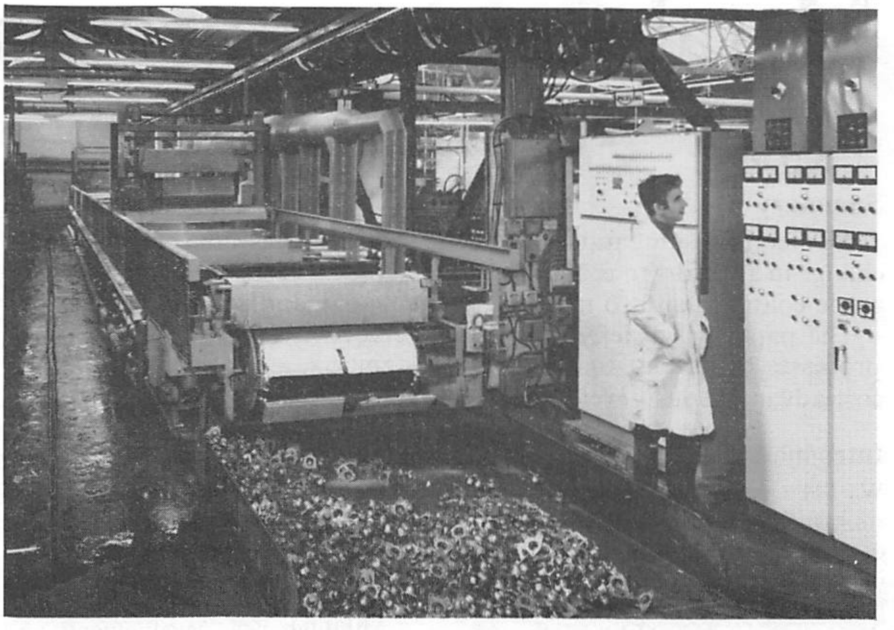


Fig 1 Fully automatic, programme-controlled plant for zinc barrel plating at an output of 1 t/h [Source: Electroloid Ltd]

Present day metal finishing plants bear the same relationship to their predecessors as do machining centres to the old centre lathes.

Possibly not yet of value to the industry except that the plant has contributed greatly to the reduced cost of the electronic controls now increasingly fitted to agricultural products, the electronics industry has evolved a novel system of selective plating to maximise economy in expensive gold. These plants are of relatively recent introduction but may well lead to new concepts in selective electroplating in general.

Treatments for aluminium

Unlike some other forms of vehicles, the agricultural industry has not so far needed to be much concerned with weight saving, but nevertheless, the use of aluminium alloys is likely to increase. Many aluminium alloys are prone to rapid corrosion in aggressive environments but this can be retarded by suitable electro-chemical or chemical treatments. Such coatings may often be dyed with organic dyestuffs to provide an attractive range of colours. The latest development has been to substitute colourings by metal salts, these being far more light fast and durable, although as yet the colour range is restricted from bronze through to blacks. The process is finding acceptance in the motor car industry.

Autocatalytic plating

A fundamental disadvantage of all electroplating processes is that the DC plating current is affected by electromagnetic forces with the consequence that the applied coating is rarely of uniform thickness over irregular shaped articles (throwing power). This variation may be negligible with some processes such as silver or cadmium or profound as in hard chromium plating, and the deficiency has undoubtedly contributed significantly to the declining popularity of electroplating processes. DC current is a very simple and cost effective means of transferring electrons to convert salts of metals to metal form, but in some instances chemical energy can be substituted, ie in the autocatalytic, or otherwise known as electroless or EN plating processes. The most commercially developed of these processes are electroless copper and electroless nickel. Electroless copper is vital to printed circuits and the "chip" industry, but electroless nickel finds more widespread engineering applications, often as an alternative to hard chromium. Electroless nickel is applied with great precision and uniformity wherever the solution may make unrestricted contact with the metal

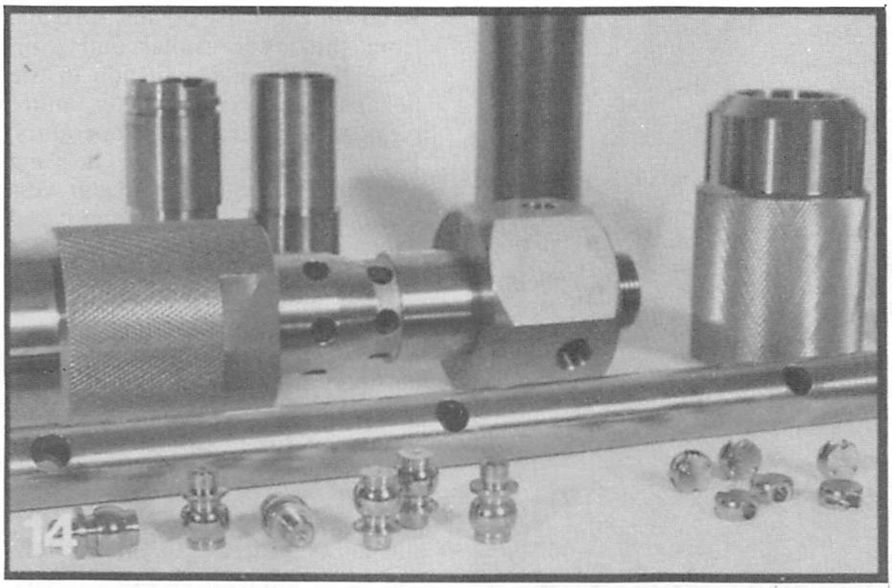


Fig 2 A range of components finished by electroless nickel plating for the gas, automotive and defence industries [Source: Montgomery Plating Co Ltd]

surface. The coatings are of a low alloy character and have a basic hardness two or three times greater than that of electroplated nickel, but may be hardened by a low temperature thermal treatment to values as great or greater than hard chromium.

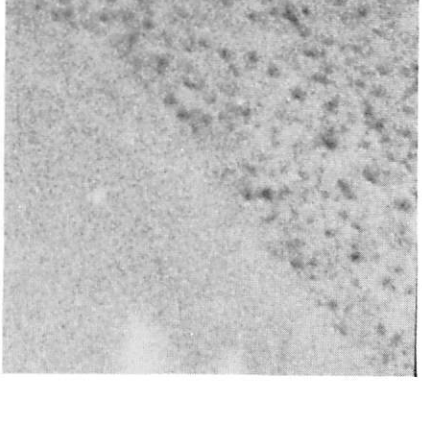
Although at present the deposition costs are about the same as for hard chromium, the avoidance of the need for often expensive, "conforming electrodes" and the elimination of post-plate sizing treatments can often mean a significant cost saving over hard chromium. Some recently introduced processes are claimed to produce coatings which have corrosion resistance superior to that of hard chrome.

This type of process also lends itself to the deposition of "composite" coatings, ie coatings containing a significant portion of very finely divided hard particles, such as aluminium oxide, tungsten carbide or most exotically diamonds, or of soft particles, such as PTFE resin or molybdenum disulphide.

The hard particle coatings are extremely abrasion resistant. Usually they are too abrasive for mating purposes, but are ideal for application to excavator bucket teeth and the like, where wear resistance without mating compatibility are feasible. The diamond/aluminium oxide type coatings are used in the modern production of laps and hones.

My Company has world exclusive rights for an electroless process which co-deposits very finely divided PTFE resins (Tulsi 1983). The coating contains between 25% and 30% of PTFE uniformly dispersed throughout the nickel coating, and the ever present PTFE film on the surface ensures constant lubrication even under cryogenic or elevated temperature situations where normal lubricants are ineffective. As the PTFE surface is worn away there is an ever present reservoir of PTFE within the coating to replenish. The coatings are not cheap on account of the high cost of the ultra fine PTFE resin, but are finding widespread adoption in the oil well and allied industries. They may well be very cost effective in your industry in special applications.

Fig 3 Photomicrograph of the electroless, poly tetra fluoro ethylene co-deposit, showing the distribution of PTFE throughout the coating



Thermal coatings

Thermal finishing processes date back to the earliest time of mankind, but with the exception of hot dip galvanising and hot tinning these earlier processes find little present-day application.

The Rover Company management were astute enough to specify hot dip galvanised coatings as a principal protective treatment on their Land Rover vehicles. The reliability of this treatment undoubtedly contributed significantly to the high regard and popularity of these rugged vehicles. Likewise galvanising is a world-wide standard treatment for the protection of electricity pylons and of railway electrification structures, and a service life expectancy in excess of 20 years is quite usual.

Galvanising is relatively cheap and the industry can process large sized structures, and I strongly recommend you to consider its adoption, if only on your special products required to operate in the most aggressive environments.

That forerunner of future change — university research — has, over the last decade or so, been increasingly concerned with the development of various types of thermally produced coatings. Oxide type protective coatings have been available for many years, but in general such coatings had relatively poor protective qualities. Now, however, we learn that at least one large motor car accessory manufacturer intends to turn away from traditional zinc and cadmium coatings in favour of a new thermal oxide coating process which it is claimed offers the greater corrosion resistance now desired by the motor car manufacturers in their zeal to increase the longevity of their products.

The relatively recent introduction of plasma arc type heat source has led to an up-dating of the older metal spraying processes. The plasma arc speeds up processing, reduces oxidisation, and enables the application of highly refractive coatings such as tungsten carbide, etc. In the aircraft industry, these sprayed coatings seem to be taking over from some of the traditional hard chromium plating applications in situations needing high wear and corrosion resistance, eg undercarriage parts.

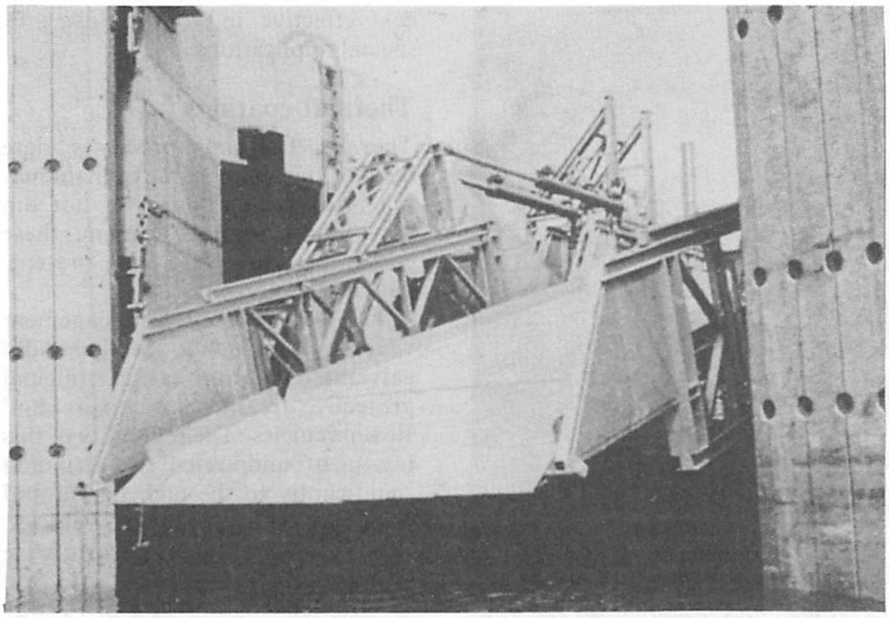


Fig 4 Galvanising is relatively cheap and simple, even for large structures such as the steel ramp for the roll-on/roll-off car ferry at Holyhead [*Source: Zinc Development Association/Galvanisers Association*]

Plasma melted coatings applied under vacuum conditions are even more versatile and reliable.

Dr J Edwards (1983) has recently presented an excellent review of these new developments, and there seems little doubt that thermal processes will play an ever increasingly important role.

Organic coatings

Organic (paint) processes are patently of great importance to the agricultural engineering industry.

In earlier times, paint and enamel materials were all blended from naturally occurring materials, but today they are almost universally manufactured from synthetic materials since these ensure greater uniformity, a wider choice of products often coupled with much improved durability, and perhaps the greatest benefit of all, suitability for forced drying and/or heat change coatings.

Again, it is significant that another major motor car accessory manufacturer plans to substitute a heavily "metal loaded" organic coating for the protection of car components.

In earlier times these zinc rich paints were usually referred to as "cold galvanising". Until recently, the finish has been relatively soft and only having a long life if applied as an undercoat to a harder finishing coat overlay. These zinc rich paints are a standard process for the refurbishment of military equipment such as radar and radio equipment when re-galvanising is impractical.

A new generation of metal plate pigments based on nickel, cupro-nickel and even stainless steel, as well as zinc, have produced harder and more durable coatings (Hart 1983).

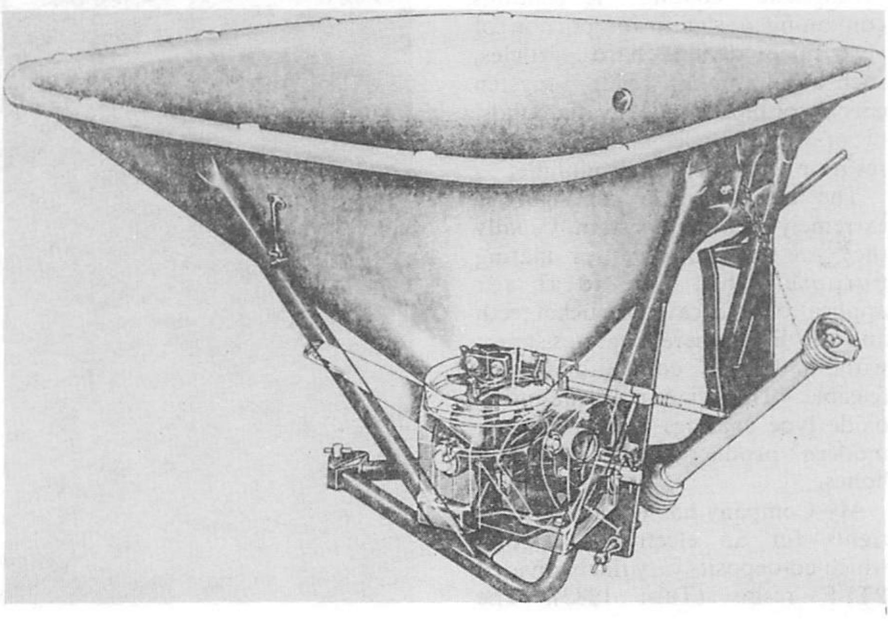
Aluminium flake is unsatisfactory as it tends to react with the other components of the paint, presenting paint storage problems.

When, two decades ago, the water based paints were introduced it was predicted that this type of formulation would soon supersede others, being of lower cost, through the substitution of cheap distilled water for expensive organic solvents, from the lower capital outlay on plant through the reduction in fire hazard, and constituting more pleasant conditions for operators. Problems soon arose in devising compatible pigments and the process was delayed for a time. Water based paints are now available based on a variety of resin systems including acrylics, polyesters, alkyds and epoxy esters. Evidence of their recent progress is now apparent in their widespread adoption for building maintenance paint materials and the trend will surely spread into other industries.

In the engineering world, the outstanding success so far for this type of material is in electro-phoretic priming, ie the application of primer coatings by an electrolytic process resembling electro plating in which the primary materials are deposited in every nook and cranny which will conduct electrical energy. Motor car manufacturers consider the benefits so great as to justify the installation of very expensive plants designed to process completely assembled body shells.

Another technique for reducing the wasteful cost of expensive organic solvents is through hot spraying. This is a process now widely adopted in the wood finishing industry which needs inexpensive high build finishes. In this type of process, the viscosity of high viscosity, low solvent, paints is reduced to a suitable value by warming the paint material in the spray gun containers. Where there is

Fig 5 The corrosive effects of fertiliser are inhibited by coating the steel frame of the Vari-spreader with a thermo-hardening powder paint [*Source: Vicon Ltd*]



a need for the application of thick organic coatings, this process should always be considered. Thick coatings are not, of course, automatically synonymous with improved service life, since such coatings are frequently more porous and detachable from the substrate.

The ultimate in solventless coatings are the so-called "plastic" coatings in which the dry paint materials are reduced to such a fine state that they can be applied by all conventional methods, as well as by the "fluidised" bed system, in which the fine powders are kept in a state of fluidised activity by the passage of air from porous tubes. In addition to traditional paint materials, conventional plastic materials as diverse as nylon to PTFE are applied with equal ease and success and thick coatings are quickly built up. A feature of this type of process is the need to heat the powder coatings to "frit" the applied material into a cohesive durable film. Disadvantages of the process, compared with traditional paint processing, are a reduced ability to rapidly change colour schemes, and some greater risk of explosion of the fine powders, unless housekeeping is of a high order. This type of coating is certainly a growth area and even now appears to have taken over some 20% of the paint industry's sales. It is being increasingly adopted by the kitchenwear and household goods industries requiring large quantities of durable painted products at minimum cost, and appears to have much scope for engineering products.

There is no doubt that thermally or stoved converted paint films are vastly more protective than air or flash dried coatings. Attendant economic advantages are a reduction in floor space allocation, avoidance of dust and dirt problems which arise whilst wet coatings dry slowly, and not least in the speed of turn round.

It is obvious that the industry, dealing as it does with heavyweight components, is unlikely to easily change to stove enamelling, but with ever increasing customer demand for greater durability and longevity of products, this change may be inevitable.

At one time, convection type ovens were the only reliable method of stoving paint finishes and this of course entails the lengthy and expensive operation of bringing the whole mass of material to the stoving

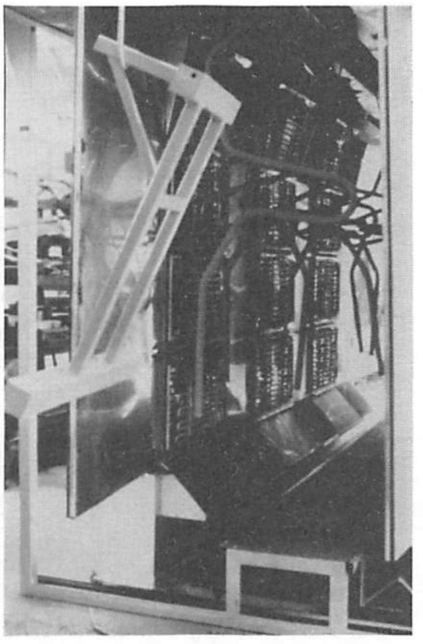


Fig 6 Paint films are cured in infra-red stoving units which treat the paint but leave the underlying metal unheated [Source: Electricity Council]

temperature and then subsequently letting it all cool again. Alternative technology has now evolved. Paint films can now be "cured" by heat induced into the paint film by infra red and ultra violet energy, so that the paint films are quickly and effectively stoved leaving the underlying metal unheated.

In the early fifties, a new generation of paint formulations were evolved in which the paint curing was by internal chemical reaction of two components mixed at the time of spraying, but until now the process has proved unreliable. A new version with a unique approach has recently been revealed in Australia (McInnes 1983) and may soon be available here. It could well be most beneficial on heavy parts of complex shape.

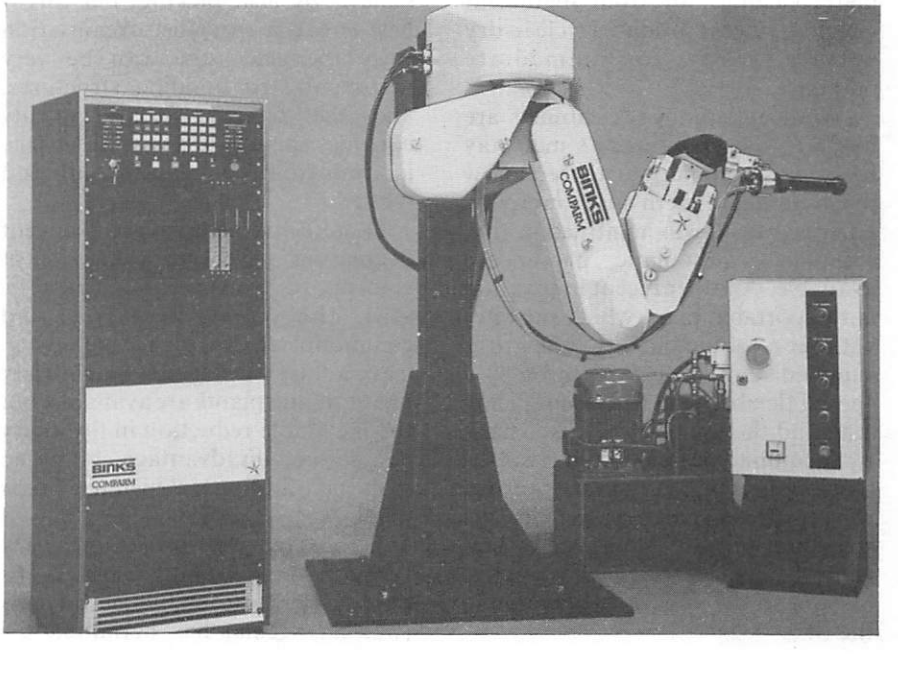
Paint application processes

The completely automated spraying of paints and powders is already well established practice where production volume justifies the high capital outlay. As products and production becomes more specialised and the cost of automated equipment is reduced, then such automatic facilities are likely to become increasingly commonplace. Paint spraying, together with welding, particularly lends itself to robotic automation.

Compressed air type spray guns are still the principal method of application, but the process is wasteful of expensive paint through "over spraying". Modern automatic spraying equipment will frequently pay for itself through more consistent and faster throughput and the considerable reduction in overspray losses from a better controlled spray pattern and job presentation.

Electrostatic spraying can virtually eliminate overspray but the method is beset by the limitation of causing the charged paint/powder particles to enter recesses and behind projections — the so-called Faraday Cage Effect. Although air and

Fig 7 Automatic spraying of paints is well established practice where production volume justifies the investment [Source: Binks-Bullows Ltd]



electrostatic spraying are quite different, it is becoming increasingly commonplace to combine them in an air assisted electric spray gun system. This is a compromise finding increasing favour.

Reference has already been made to paint application by dipping and draining, with or without electrophoretic deposition and/or electrostatic detearing, ie the removal of unsightly draining "tears" and "fat edges" by a simple electrostatic paint removal device, and where applicable is one of the most cost-effective method of applying paints.

The paint brush is as fundamental as the wheel and just about as old. In the hands of a competent and conscientious operator it still remains the cheapest, in terms of capital outlay and is a most versatile method of applying paint to large structures. In these days this is all too often overlooked.

Pre-Treatment

No finishing process whether it be electroplating, chemical treatment, or organic coating will be effective unless it is applied on to a suitably prepared receptive substrate to permit atom to atom bonding.

Before cleaning, the metal surface will inevitably be contaminated by a combination of mill scale, rust, metal dust, grease, water and many other types of debris.

Despite the fact that gritblasting is very crude, often unpleasant, and expensive to operate, it is still the preferred preparatory treatment where heavy scale is present, which can arise from the use of hot rolled plate, castings, or from inefficient welding, since it produces a clean dry surface ready for immediate painting.

"Walk in" rooms or cabinets are likely to be the industry's mainstay for years to come, but there is now much more modern and improved equipment; where quantities justify, completely automatic plants are available. Another recent innovation is the portable plant which operates without a cabinet facility. The grit is supplied to the surface through a special flexible head with a soft facing seal, and the used grit is sucked back by vacuum to be graded and returned by closed circuit to the reservoir for re-use. Designed for use in the structural industry, this type of unit could be considered for the selective blasting of say large welded units and the like.

Fig 8 Portable, self-contained, gritblasting unit for preparatory treatment of metal surfaces

Unit costing is clearly confirming that it is economic to replace the high cost of shotblasting through the use of unscaled metal stock, arc welding and other forms of scale reducing techniques.

A related process, though unsuitable for the bulk removal of heavy scale is wet blasting in which much finer abrasives such as aluminium oxide suspended in water are the cleaning media. The process constitutes an ideal versatile pre-treatment before "wet" processes. The water exerts a considerable cushioning benefit so the process is suitable for fragile items. It can be combined with a phosphating treatment.

The cheapest way of removing scale is by acid picking, but this is best left to a specialist organisation since the acid fume can be very detrimental to building structures, and the treated surface readily corrodes again unless the acid surface is immediately neutralised and treated.

Despite its toxic hazard "solvent degreasing" using one of the range of chlorinated hydrocarbon media, is still the most versatile and commonplace degreasing method to leave a "dry" surface. A wide variety of automatic plants are available, but the inevitable reduction in flexibility is a serious disadvantage compared with the traditional "open top" type plant.

Before any "wet" processing, some form of alkali cleaning is usual. The development of stable surfactants (wetting agents) has permitted the evolution of a new range of cost effective formulations with longer life before grease saturation, and which operate at lower temperatures.

"Emulsion" type cleaners — closely related to the traditional machine shop "suds" emulsion — and which are potentially cheaper than alkali formulations, have not yet found widespread acceptance. Their effective life is still short and their disposal presents environmental problems.

"Live" steam is a most effective cleaning agent. Portable units based upon electric steam raisers have already found widespread use in the road haulage industry for vehicle cleaning, and might be worthy of greater engineering application, particularly for the servicing of units after use.

Most of the usual synthetic paint formulations are basically incompatible with metal surfaces if applied directly, and either a barrier coating such as phosphating, or a primer coat, or both, is essential to best adhesion in service.

In phosphating, the cleaned metal surface is immersed in, or sprayed with, a specially formulated metal phosphate solution which in a critically balanced chemical reaction, first etches the metal surface and then deposits a relatively inert metal phosphate coating. Still the most effective and often insisted upon in many Government contracts, the early formulations have been updated by the inclusion of "accelerators" so that under certain ideal conditions the process time is

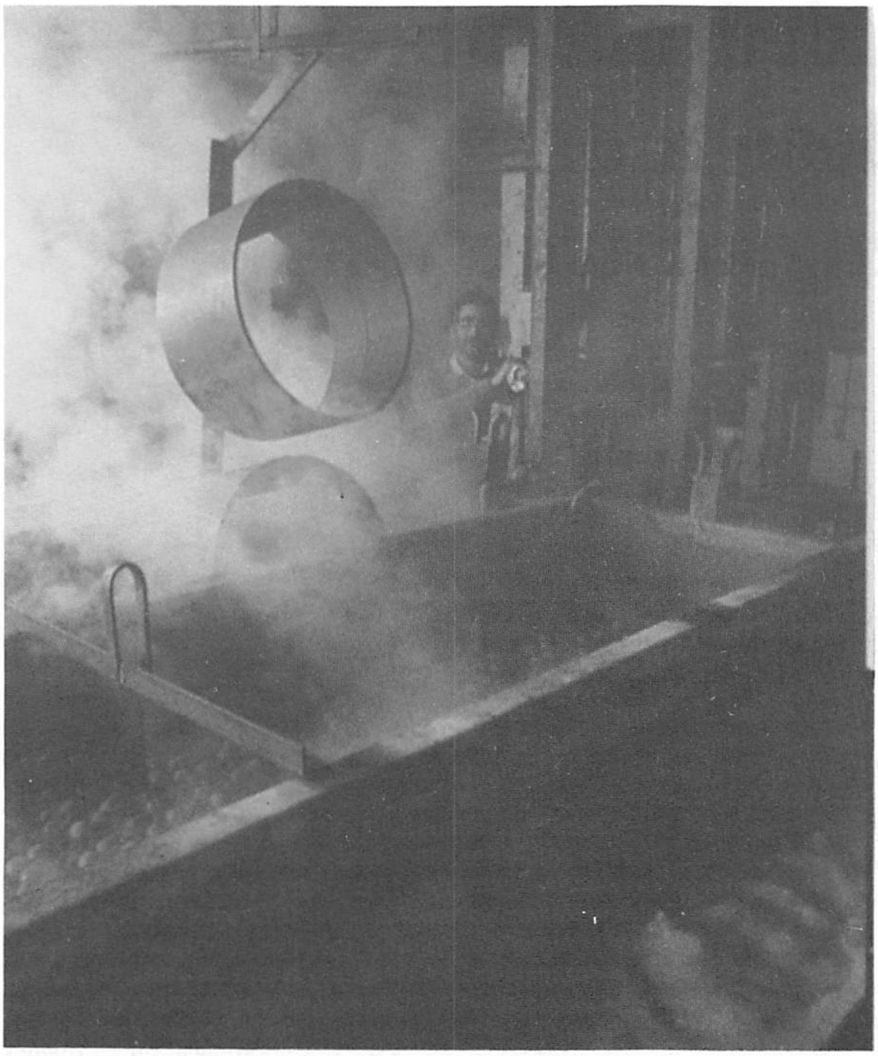


Fig 9 Phosphating two large oil pipeline couplings to retard corrosion under paint coatings [Source: Montgomery Plating Co Ltd]

reduced to a matter of minutes, with consequent economies, but of course produce much thinner coatings. Properly carried out phosphating is a most effective way of retarding corrosion under paint coatings, but all too often the process parameters are not satisfied with disappointing results. The coating should be fine with no glister.

The combined emulsion degreasing/phosphating formulations still need considerable improvement before they are worthy of adoption.

Primers are special paint formulations embodying oxidising materials such as chromates, oxides of iron, etc, which have a beneficial reaction with the metal surface thereby improving adhesion and retarding corrosion at the interface.

Even more effective are the modern etch primers in which a small quantity of phosphoric acid is included in the primer formulation. This produces a chemical reaction with the metal similar to that of conventional phosphating. At one time, the primer was supplied in "two pack" systems which were mixed just prior to use and had a relatively short mixed life, but more stable resins have been evolved and "one pack" formulations are now usual.

The zinc or other metal rich paint undercoat formulations referred to earlier are most beneficial for plant required to operate in the most adverse environments such as the tropics or arctic areas.

As with primers, the top or finishing coat paint formulations have also been greatly improved so that the modern agricultural engineer has access to highly developed and effective paint systems which will bring his products great credit and long and satisfactory life in the hands of his customer.

Conclusions

1 Throughout its history the metal, or more aptly the product, finishing industry has been characterised by the readiness in which it has adapted itself to change, whether by improved process or plant, and there is no reason to believe that the changes of the next two decades will be any less radical than those of the past two.

2 The industry is by its very nature extremely cost effective, since it takes expensive materials, be they metals or organic, and economically spreads them over large surface areas. Consider how much more effective is one pound of nickel applied by plating compared to the same weight to make stainless steel. Furthermore, the industry enables goods to be produced in cost effective functional materials with little or no aesthetic appeal and then to bestow them with a durable sales attractive finish.

3 In general the cost of product finishing is only a tiny fraction of the total sales costs, yet its benefits are fundamental to successful sales. Far too often manufacturers, in their endeavour to save the proverbial "ha'porth of tar", spoil a very good ship through ineffective low cost finishing — witness what happened to the motor car industry when misguidedly it adopted a policy of cost cutting.

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Computer aided manufacture — converting design data into manufacturing instructions

P Marshall

Summary

WHILST much publicity has been given to the development and use of interactive computer aided design (CAD) systems, relatively little attention has been paid to the application of computers to the complementary and essential production engineering activities which take place before production can actually begin. These activities include method study, process planning and estimating, numerical control (NC) programming and prove-out, capacity planning and scheduling, etc. For these functions, too, the modern digital computer with appropriate software can now provide effective aid in terms of time and cost reduction.

British organisations have played a leading role in developing software and systems for all these pre-production phases of computer aided manufacture (CAM) and several of these will be referred to in the presentation. Reference will also be made to the work undertaken by Production Engineering Research Association in the field of mechanical engineering on the concept of a Linked Software System, whereby various existing CAD/CAM modules can be linked together into a comprehensive, integrated system for the automatic conversion of design data, into manufacturing instructions, ready for issue to the shop floor.

Introduction and background

DURING the evolution of CAD/CAM systems over the past two or three decades, it is interesting to note how independent developments which began at completely opposite ends of the CAD/CAM spectrum have gradually approached each other, and yet only in 1984 is a complete link-up over a broad field of engineering becoming a reality.

Apart from the use of computers for the purpose of calculation, computer aided design as we know it today did not come into regular use until the 1960s when the computer was successfully linked to a graphic display screen, so that under the direction of a trained engineer, and with appropriate software, it became possible to create pictorial models of two and three dimensional shapes on the screen — interactive computer aided design.

As a quite separate development, in the late 1950s and early 60s following the introduction of NC machine tools into our workshops, came the development of computer aided NC programming systems, which enabled major reductions to be achieved in the time and cost necessary to write an NC program and prepare an NC tape.

Perhaps not surprisingly most of the early developments in both these areas emanated from what might be generally described as the 'exotic' end of engineering, aero-space, missile, defence projects, and in both areas British companies played a leading part.

In these types of industry it is undoubtedly true that two of the major problem areas in creating and building a new product, in terms of the time and manpower involved, are centred around the functions of design and the actual machining of complex components and assemblies. It was therefore considered in many quarters that once the computer had been successfully harnessed to these two areas that all the major CAD/CAM application problems had been solved for all types of industry; this is not so.

In the vast majority of engineering companies, including those in the agricultural engineering industry, the actual amount of time and effort involved in conceptual, creative design is quite small, and machining cycles on all but a few major components tend to be short, of the order of minutes. Even so, it is very often a matter of some days or weeks before production work can commence on a new order, and possibly even longer before that order is completely manufactured and ready for despatch to the customer.

It is of interest to break-down the functional activities in the pre-production and production areas, in order to assess:

a) how computer aids can be used to make the activities more cost-effective;
b) what type of computer aids are currently available; and
c) how the available computer aids fit together into a coherent CAD/CAM system.

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Design and manufacturing functions

The main engineering functions involved in the creation and subsequent conversion of design data into manufacturing instructions are listed in fig 1. Clearly the extent, or even the formal existence, of each of these functions depends on a variety of company and product-related factors, but, with the possible exception of the NC functions (ie when no such machines are in use), all the activities have to be undertaken as part of the overall process of design and manufacture.

It may be of some interest and significance for individual companies to calculate how many personnel (direct and indirect) are now involved in the pre-production activities numbered 1 to 8, as opposed to those associated with the actual production processes (item 9); and to compare the ratio which applied to their company say 20 years ago. In almost all cases, the ratio of pre-production to production personnel will have increased, mainly as a result of two interacting factors. The first one relates to the continuing increase of all types of automation techniques on the shop floor with subsequent reductions in the number of direct operatives required. The second factor, mainly consequent upon the first, is that in our well-intended desire to improve the efficiency of the directly productive processes, we have created an ever-increasing number and variety of pre-production functions to determine what should be done on the shop floor, when it should be done, on what machines and in what sequence it should be carried out, etc. So that when the instructions reach the shop everything can swing into action without delay. Basically this is a very laudable objective, but what has tended to be lost sight of is that we have been solving one problem and at the same time creating another. So that we now have veritable 'armies' of trained engineers engaged on a series of pre-production tasks, armed in most cases with very little more than a pocket calculator. Examination of most of the pre-production functions — after the creative design stage — reveals a high proportion of work which, at its simplest, is straightforward clerical work and contains many other low-technology aspects which do not fully utilise the skill, qualification and

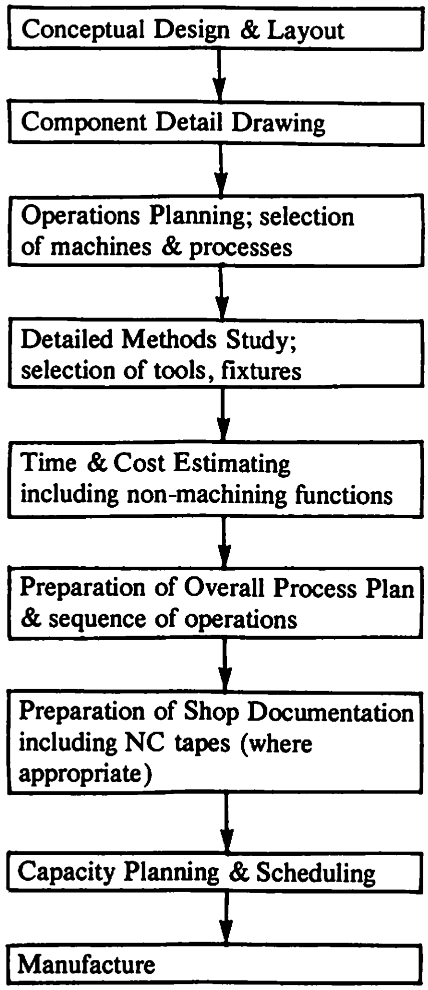


Fig 1 Typical sequence of engineering activities

training of the type of engineer who is usually employed. Much of the work involves reference to national or company standards, retrieval of previously produced documents for comparison, arrangement of data in a stylised format, and in the case of many 'manual' scheduling systems involvement in a sort of 'jig-saw puzzle' game concerned with the arrangement (and rearrangement) of numerous pieces of card in an attempt (often futile) to keep track of what is actually going on in the shop — when the real task is planning, scheduling, monitoring and controlling shop floor production.

In fact, most of these pre-production functions have some or all of the following characteristics; they are:

manpower intensive;
time consuming;
repetitive;
tedious; and
prone-to-error.

Invariably, they involve logical decision-making based on a pre-determined set of 'rules', calculation, storage, retrieval and modification or editing; in short they are tailor-made for the modern digital computer.

Available CAD/CAM systems

CAD/CAM systems available today provide:

either

a) an aid to the engineer which enables him interactively to combine his skill with the speed, memory and computational ability of the computer, generally involving the use of a VDU and keyboard as the communication point between man and computer;

or

b) a computerised and automated batch processing facility which form a relatively small amount of input data will complete a sequence of tasks previously undertaken by the engineer, according to a set of logical rules which have been built into the computer program.

In the case of the interactive approach, the systems tend to be adaptable to a very wide range of tasks — on the basis that much of the critical decision taking process is carried out by the operator. Whereas in the case of the data-input systems, the very fact that the computer system has to make an often complex series of decisions tends to limit their application to specific types of activity.

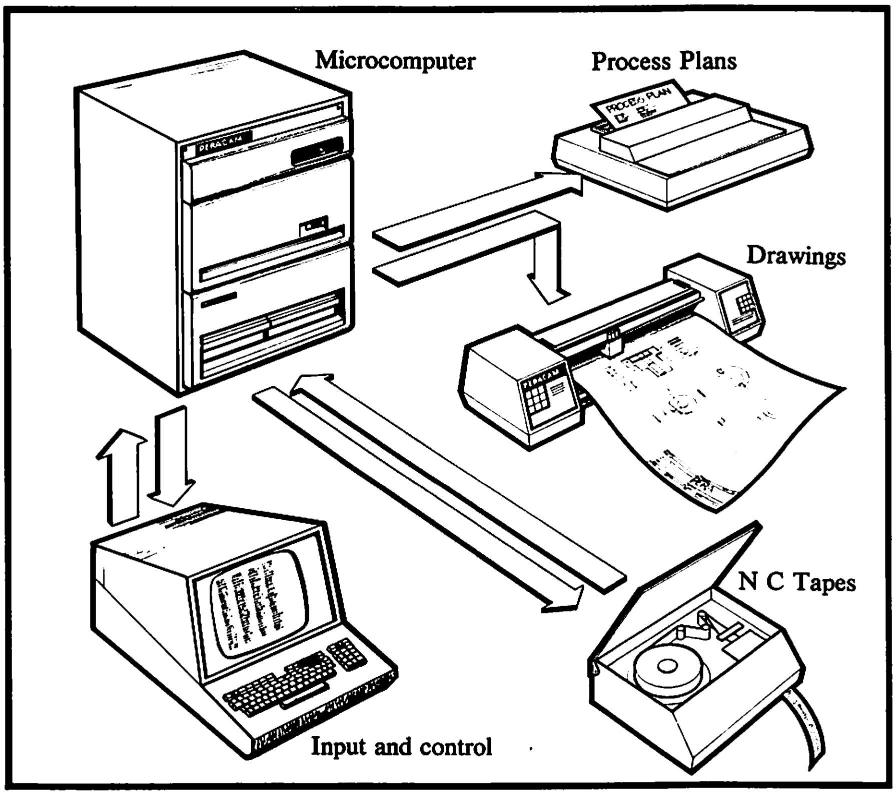
There are variations and mixtures of both techniques to be found in systems available today, and it is most important for the potential user to ensure that he selects the best sort of system for his range of applications. It is often a useful exercise for a potential user to compile a comprehensive list of the tasks for which he is seeking the assistance of a CAD/CAM system, and then make a careful assessment which tasks the computer will be doing, and which tasks he will have to undertake. This can be a very informative exercise in terms of making the most cost-effective purchase and avoiding the all-too-easy pitfall of using a powerful and expensive computer system to undertake relatively trivial tasks — the well known situation of using a sledge-hammer to crack a nut.

Computer aided design and drawing

Undoubtedly this is one of the most appropriate and best exploited areas for the application of interactive computation. The actual function of creative design in mechanical engineering requires a considerable amount of conceptual thinking, decision making and aesthetic (as well as numerical) judgement; qualities still found in abundance in men — particularly engineers dare we say — but as yet not to be found in the software capabilities of modern CAD systems. Interactive CAD systems are now available in a whole range of packages varying from relatively low-cost 2D wire-frame systems to expensive and extremely powerful 3D systems incorporating true solid modelling facilities, alongside numerous other features to facilitate the rapid creation, modification, storage, retrieval and editing of complex designs. These types of systems tend to be most cost effective where a company produces a coherent and evolutionary range of products, such that as each design is completed it can be stored on a disc file and then recalled as a basis for, or simply as an aid to, the next design.

It is difficult, if not impossible, to make an absolute distinction between what constitutes a design drawing and what constitutes a detail drawing in the mechanical engineering field. But generally design drawings are composed of a large number of components in a general arrangement or layout with few or no dimensions. Detail drawings are invariably of one component plus a complete set of dimensions together with all the other engineering attributes (tolerance, surface finish, concentricity, hardness, etc), which need to be specified for the purposes of manufacture. In this latter context the detail drawing contains clear indications of the anticipated methods of manufacture, ie the attributes specified by the draughtsman require particular types of production methods if they are to be achieved. It is particularly important that the relationship between these attributes and the general component geometry should be linked within the computer software if we are to link the design and drawing phases (numbered 1 and 2 in fig 1), with the subsequent functions of operations planning, method study, estimating, process planning — numbered 3 to 6 in fig 1. It was as a result of recognising this situation that the system developed by Production Engineering Research Association for the production of detail drawings, PADDS, (see fig 2), was based on the concept of getting into the computer a complete, but abbreviated, description of the engineering component. With appropriate software, this not only enables the system to automatically produce a fully dimensioned multi-view drawing, but also ensures that the component description now captive inside the computer can, using additional software modules, be operated on again successively for the remaining pre-production processes.

Fig 2 PERACAM system for producing detail drawings, process plans and numerical control tapes from a single set of input data



Computer aided process planning and estimating

As with computer aided design techniques, it is possible to take either the inter-active, semi-automatic method of generating process plans, or a data-input, automatic batch processing method. In the former instance, the technique is readily adaptable to a wide range of manufacturing processes, but tends to depend rather heavily on the use of extensive data files — which may have to be built up to suit each company. In the latter case, the need for large data files is much reduced, but the range of application is necessarily limited by the capabilities of the operating software which involves the building-in of extensive logic routines for each different type of manufacturing process.

Several well established inter-active computer aided planning and estimating systems are available on the market mostly developed by UK companies. A particular advantage of these systems is that the estimates which they produce (based on company or national standards) tend to be consistent, and as a result once accepted on the shop floor are rarely thereafter the subject of dispute — a most important factor. Additionally significant time and cost savings can be achieved using these techniques since they take full advantage of the ability of the modern computer to calculate, store and retrieve information at a rate far in excess of that which people can achieve manually.

An alternative, but nonetheless complementary approach is provided by the Production Engineering Research Association's PROPLAN, which, using the same basic data required to automatically produce a detail drawing via the PADDS processor, will automatically work out the manufacturing strategy for a considerable range of machined parts. In this context manufacturing strategy covers the type of operations to be carried out, the machines to be used, the tools to be used on the machines selected, the sequence of differing types of operations (eg turn, mill, drill, bore, grind, etc) an indication of the method of location and clamping and if required a series of stage drawings showing the evolving shape of a component as it passes through each machining stage. In fact the decisions taken by PROPLAN constitute the majority of the decisions required to be made by the engineer when using an interactive computer aided planning and estimating system. Clearly, as previously stated, these two techniques are complementary and the Production Engineering Research Association in conjunction with the suppliers of computer aided planning and estimating systems, have explored the development of a software interface, and already achieved considerable success in this respect.

In conjunction with either or both of these types of system, a user can make further improvements in shop floor production efficiency through the use of a computerised bank of high quality machining data; data giving proven recommendations on feeds and speeds for a wide range of machining operations and material combinations. Staff of the Production Engineering Research Association have been compiling such a computerised data bank (MACBANK) for many years in a form which makes it readily adaptable into other computer based systems, or directly accessible on a stand-alone basis on a micro-computer.

Computer aided numerical control tape preparation

This is perhaps the most extensively developed and widely used of all CAD/CAM techniques and the potential user has a very wide range of systems to choose from varying from powerful and relatively expensive 3D systems running on large main-frame computers, down to the purpose-designed 2D systems which can be operated using an 8-bit micro. Possibly one of the most significant changes in computer based numerical control programming systems over the past ten years has been the more general introduction of graphics facilities. These not only provide alternative methods of preparing numerical control or computer numerical control programs on an interactive basis, but also (and probably more important in economic terms), provide valuable assistance in the business of tape prove-out, and thus save time which would otherwise be spent on shop floor trials, with the consequent loss of expensive production hours.

A further possible use of the graphics facility relates to the ability to reproduce multiple component outlines in different positions and different orientations in order to optimise component nesting for punching or flame cutting — a feature very relevant to the needs of the agricultural engineering industry.

Figure 3 shows a set of component parts for some agricultural equipment which were produced using the graphics/drawing facility in the PERA computer aided numerical control package CONPIC.

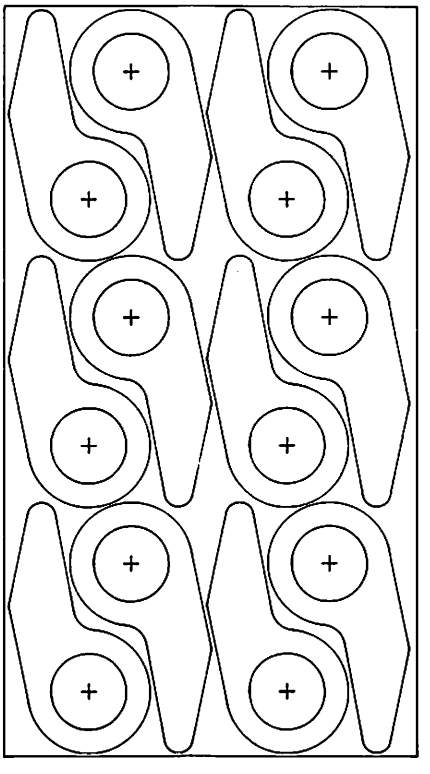


Fig 3 Latch levers, computer nested using CONPIC

Computer aided capacity planning and scheduling

For many years now, there have been available to industry a variety of production control systems concerned with functions such as stock control and material requirements planning, and some of these systems monitor what has happened in production in an after-the-event fashion when they are coupled to an adequate system of shop floor data collection. The majority of systems in use have been devised by one or other of the major computer suppliers and thus tend to be computer dependent; a fact which is not always attractive to the potential user who wishes to choose the system most appropriate to his production control problems and not necessarily the system most convenient for his existing computer. However, most of the systems of this type are well developed and do provide much needed information regarding stock, materials and bought-out items which are required for the purposes of production.

In many cases, though the systems fall short of the real problems facing shop floor production management who need to plan production so that manufacturing start and finish times, through-put times, due-date requirements, batch quantities, etc, are properly matched to the production capability and capacity, whilst ensuring that the sequence and delivery of jobs is in accordance with management requirements. Undoubtedly one of the most significant problems — frequently not covered by most existing systems — is that concerned with labour utilisation, including individual skills, flexibility, efficiency factors and the actual available capacities from the interdependent labour and machine relationships. The production manager not only requires the right number of men and machines, he requires the men with the skills appropriate to the machines available and the work scheduled to be completed.

Arising from considerable analysis of the situation, the Production Engineering Research Association has developed, over a period of years, the 4W (Who does What, Where & When) system, comprising a range of software modules which can be readily matched to the planning and scheduling needs of an individual company, and easily adapted to run on almost all mainframe and mini-computers. The system virtually enables a computer model of the factory to be created and then once having compiled a capacity, plan or schedule, the powerful 'What If' facility can be used to study the effects of changes in order sequence, machine usage, manpower/skill availability, etc. The information is practicable and realistic and enables management to both forecast and actually achieve delivery dates.

The linked software system

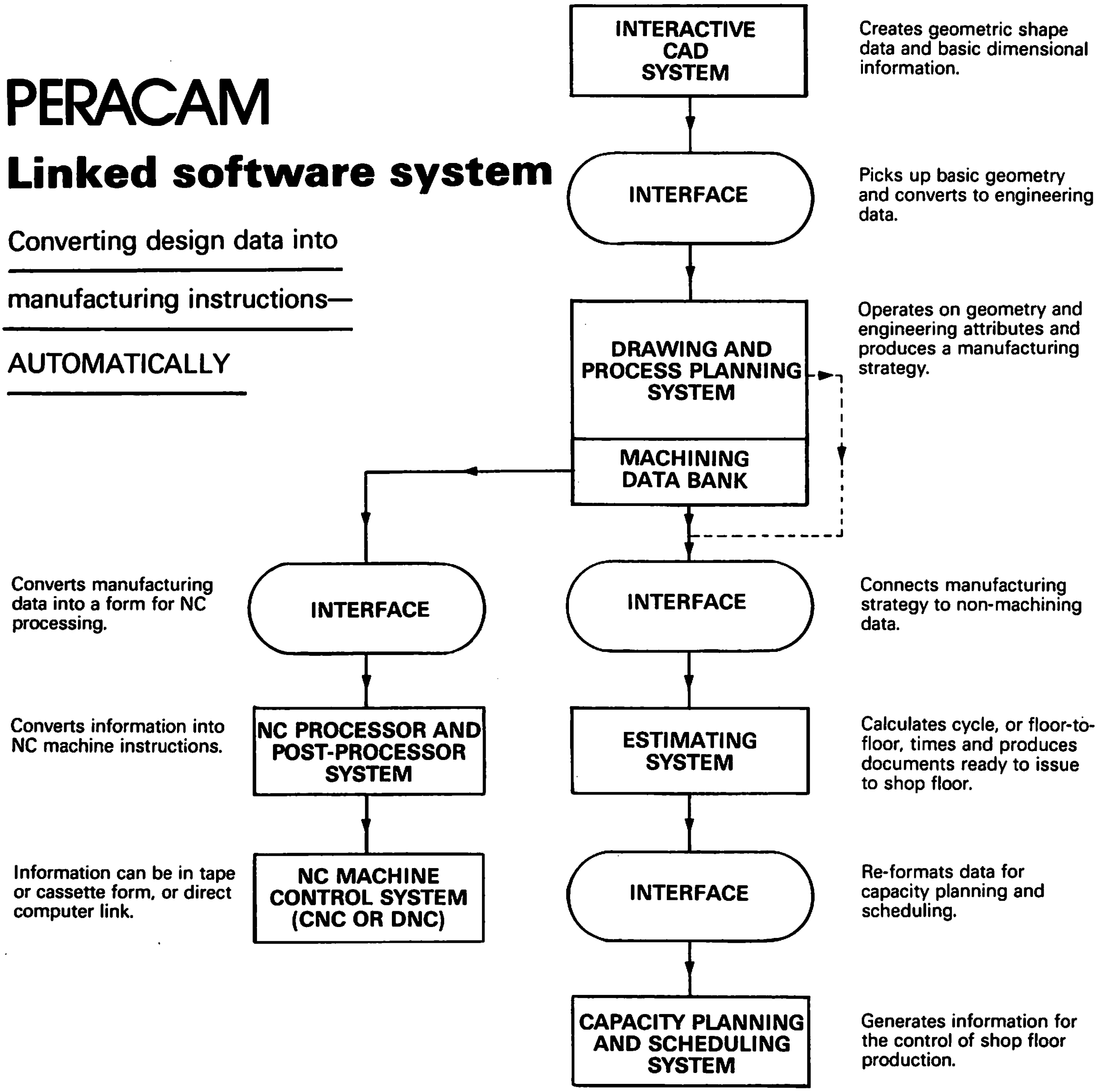
Undoubtedly there exist some (and in many cases a variety of) computer aids relevant to all the pre-production functions illustrated in fig 1. The matter which has been increasingly occupying the attention of some CAD/CAM system designers and users is if or how all these elements can be linked together into a coherent system which will provide a quick and cost-effective means of converting design data into manufacturing instructions, ready to issue to the shop floor in whatever form required.

There are many problems to be faced in terms of compatibility of different computer systems and hardware peripherals, compatibility of computer languages, compatibility of software systems in terms of their input requirements, structure and logic, and last but not least the compatibility of each and all elements of the system with the widely differing requirements of the various sectors of industry.

What does seem practicable is to take a particular sector or type of industry, say mechanical engineering, or civil engineering or electrical engineering, and develop a complete system for that sector. Having decided on a sector then it is almost certainly necessary to select a particular software language; one that is both appropriate to the type of computation involved and is common to most if not all makes of computers in regular use. Thereafter it is mainly a question of ensuring that the various software modules are readily portable, and that the style and form of input and output is clearly defined so as to facilitate the writing of software interfaces. This will enable the modules to be linked together, but will also allow them each to be used in a stand-alone manner when desired.

This is the approach that the Production Engineering Research Association has taken in the field of

Fig 4 The requirements of a CAD/CAM linked software system



mechanical engineering and with the co-operation of several suppliers of UK CAD and CAM packages, together with the support of the Department of Industry, is well advanced in the development of the necessary interfaces to make a complete linked software system. A block diagram of the system is shown in fig 4 and it is intended that it should accommodate as many as possible of the CAD and CAM elements developed by UK organisations.

The successful completion of such integrated systems will make a reality of the idea of the automatic conversion of design data into manufacturing instructions. This offers the prospects of significant cost savings, and perhaps equally important big reductions in lead time; vitally necessary if industry is to take full advantage of the speed and flexibility achievable through the use of the advanced manufacturing systems and techniques now available on the shop floor.

Prospects for CAD/CAM in agricultural engineering

All the techniques referred to are functionally relevant to the agricultural engieering industries. However, it is recognised that with some exceptions the majority of companies in that industry are relatively small, and in many instances it must seem to company management that the technological and financial investment is daunting to say the least. This does not mean however that all companies large and small should delay any longer making a start. The continuing fall in the cost of computer hardware and the increasing variety of software packages available means that a company can begin with an investment of less than £10,000 in the computer aided numerical control field, and probably as little as £30,000 in the CAD field; investments which can show a pay-back in a few years providing the right equipment is chosen for the right application.

Knowing where to begin can in fact be difficult but this too no longer needs to be a reason for putting off making a start. The Department of Trade & Industry offer assistance in a variety of ways, some generalised in the form of demonstration and awareness units, (practical experience centres), and others more specialised towards the individual needs of each company. For example, the CAD/CAM consultancy scheme enables companies to employ the services of a Department of Trade and Industry authorised consultant (such as the Production Engineering Research Association), involving a grant to the company of up to £3,000. During the course of such a study the consultant should be able to identify the most appropriate area for applying CAD/CAM techniques together with an indication of the type and cost of equipment required and the likely return on investment.

Further grants of 50% of the cost of the project planning stage are available, and a final application for assistance with actual purchase of a system can currently attract a grant of up to 33⅓%.

All companies in the agricultural engineering industry, large and small, should at least take advantage of the awareness and consultancy schemes, in order to see the way ahead using the latest techniques and formulate a step-by-step plan which will enable them to maintain and possibly improve their profitability, and ensure that their competitors — particularly those from abroad — do not make irreversible penetrations into their existing markets.

Fuel sources for field machines

D Buckley-Golder and K Langley

Summary
THIS paper describes the future prospects for making synthetic fuels for operating field machines when oil is no longer available. The background to the oil crisis is first reviewed briefly. Various options for synthetic fuels are then discussed. These include synthetic fuels both from fossil sources, such as coal and natural gas, and from renewable sources using agricultural feedstocks. Although synthetic fuels are not economic at present, they could become economic in future if oil prices rise sufficiently.

Deborah Buckley-Golder

Kevin Langley

Introduction
THE question: 'what do we do when the oil runs out?' has been asked many times in the last 10 years or so, since the Organisation of Petroleum Exporting Countries discovered the political and economic power of controlling the oil flow. For stationary applications of energy, alternatives to oil such as coal, natural gas and electricity are easily substituted. However, fuels for mobile power, whether transport vehicles or field machines, are more difficult to substitute, since they must be easily handled and stored.

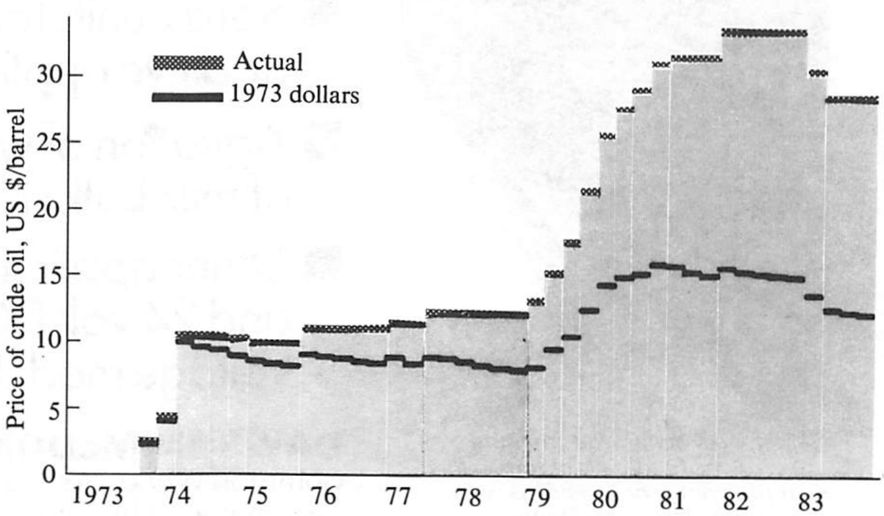
In this paper, we first review briefly the background to the oil crisis and then examine the prospects for obtaining fuels from fossil sources such as unconventional oil, coal and natural gas. Subsequently, we discuss the technical possibilities for exploiting a renewable source of fuels — biomass.

The background of the oil crisis
The *BP Statistical Review of World Energy* (BP 1984) provides some illuminating data which helps to trace the history of the oil crisis. The first oil crisis was sparked off in 1973 by the Organisation of Petroleum Exporting Countries increasing the price of crude oil five-fold, from US $2/barrel to around US $10/barrel. The new price held steady until 1979, and then increased three-fold to over US $30/barrel. Since then the price has slipped back a little, and there is now a considerable glut of oil on the market. The 1970s was also a period of high inflation. The extent to which this was caused directly by the oil price rise is a matter for some debate. However, it can be seen from figure 1 that the effects of inflation helped to mitigate the first price rise, so that the oil price in terms of 1973 dollars actually fell by about 20% between 1974 and 1979, even though it continued to rise in nominal terms.

Figure 2 shows the effect that these price moves had on the trend of world oil consumption. It can be seen that the first price shock brought about a short-lived fall in consumption. By 1975, consumption had begun to increase again. The 1979 oil price shock has produced a more durable fall in consumption, partly due to the effects of the recession and partly to fuel substitution.

The trend in world oil production is also very illuminating (fig 3). Output from non-OPEC sources

Fig 1 Arabian Light prices: actual and in 1973 dollars (Source: BP Statistical Review of World Energy)



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This paper was presented at the East Midlands Branch Conference entitled: Power for Mechanised Farming in the 21st century, held at the University of Nottingham on 27 September 1984.

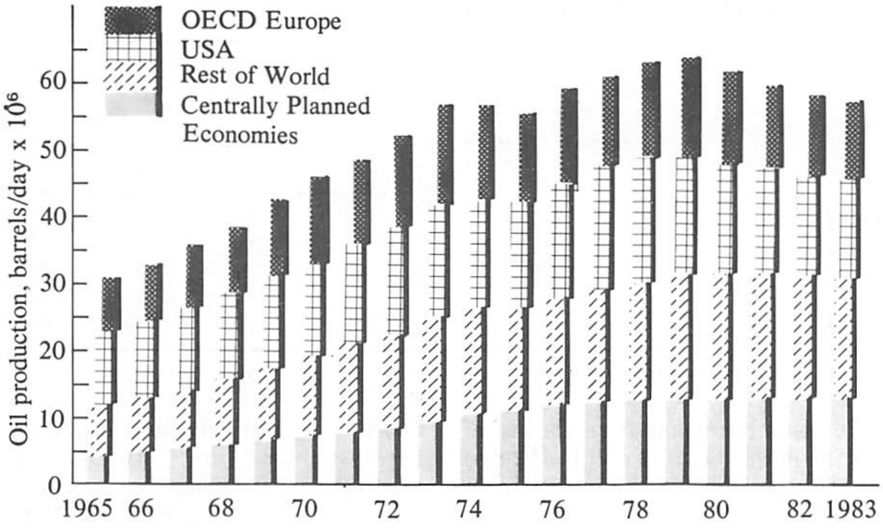


Fig 2 Oil consumption by area

Fig 3 Oil production by area (Source: BP Statistical Review of World Energy)

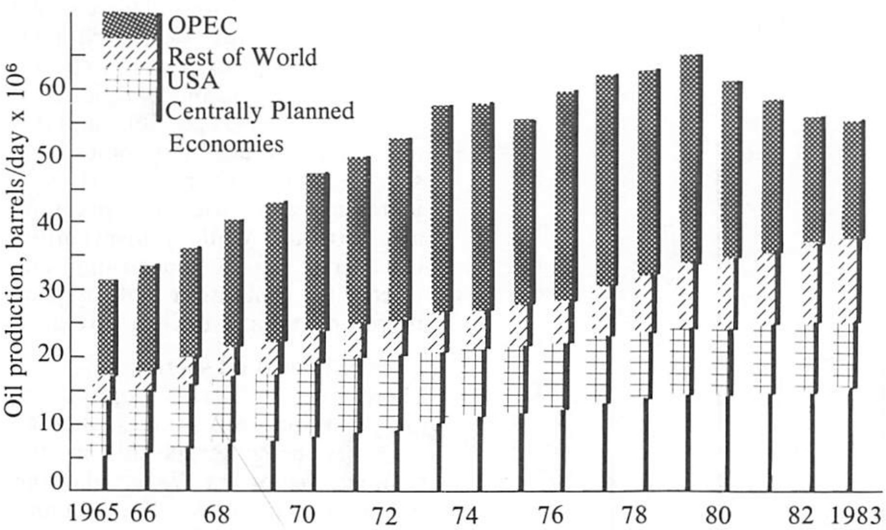
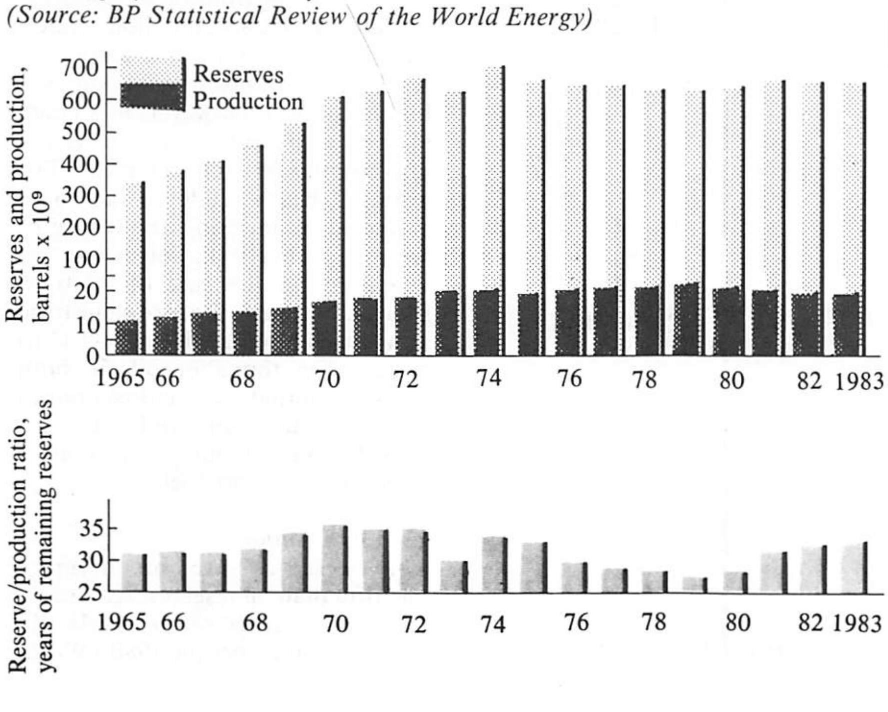


Fig 4 Oil reserves production and reserve/production ratios. In the upper graph, the vertical scale has been expanded between 0 and 25 to allow production volumes to be displayed more clearly.
(Source: BP Statistical Review of the World Energy)



continued to increase throughout the period. In 1973, OPEC produced over half of the total world production. By last year the proportion of OPEC production had fallen to about one third. Thus OPEC's monopoly power has to some extent been blunted, at least for the time being.

Oil is a limited resource and must eventually run out. However, there is no easy answer to the question 'how long will it last?' As it becomes more scarce, the price will rise, encouraging both greater economy in its use and the search for alternatives.

Existing reserves of oil are equivalent to about 30 years' supply at the current rate of consumption. Of course, this is simply a ratio of known reserves to current production; it does not mean that the oil will suddenly run out in 2014. Figure 4 shows that, since 1965, new finds of oil have more or less kept pace with consumption, so that the ratio of reserves to production has remained fairly steady.

Figure 5 shows where these reserves are located; note that the overwhelming bulk of proven reserves is in the Middle East. The extent to which new reserves can be found, especially in less politically sensitive areas, remains to be seen.

Synthetic fuels from fossil sources

There are, however, a number of options for producing transport fuels by chemical processing of other fossil fuel resources, viz:

- upgrading of residual oil;
- exploitation of unconventional oil sources
  - very heavy crude oil (< 20° API gravity),
  - tar sands,
  - shale oil;
- coal liquefaction;
- natural gas
  - direct use in pressure cylinders,
  - conversion to methanol or synthetic petrol.

Residual oil upgrading

When crude oil is processed in a refinery, it is first separated by fractional distillation into its constituent components, which are subsequently modified to meet market requirements. The various different kinds of product can be grouped as in table 1.

Table 1 Approximate boiling point of distillation fractions

Product type	*Approx. boiling point, °C*
Light distillates (petrol, naphtha)	<150
Middle distillates (kerosene, diesel)	150–350
Residual oil	>350

The 'straight run' yield of each category of product obtained by fractional distillation of Arabian Light crude oil at atmospheric pressure is shown in table 2. This is compared with the final refinery yields for both the UK and the USA in 1972 and 1983.

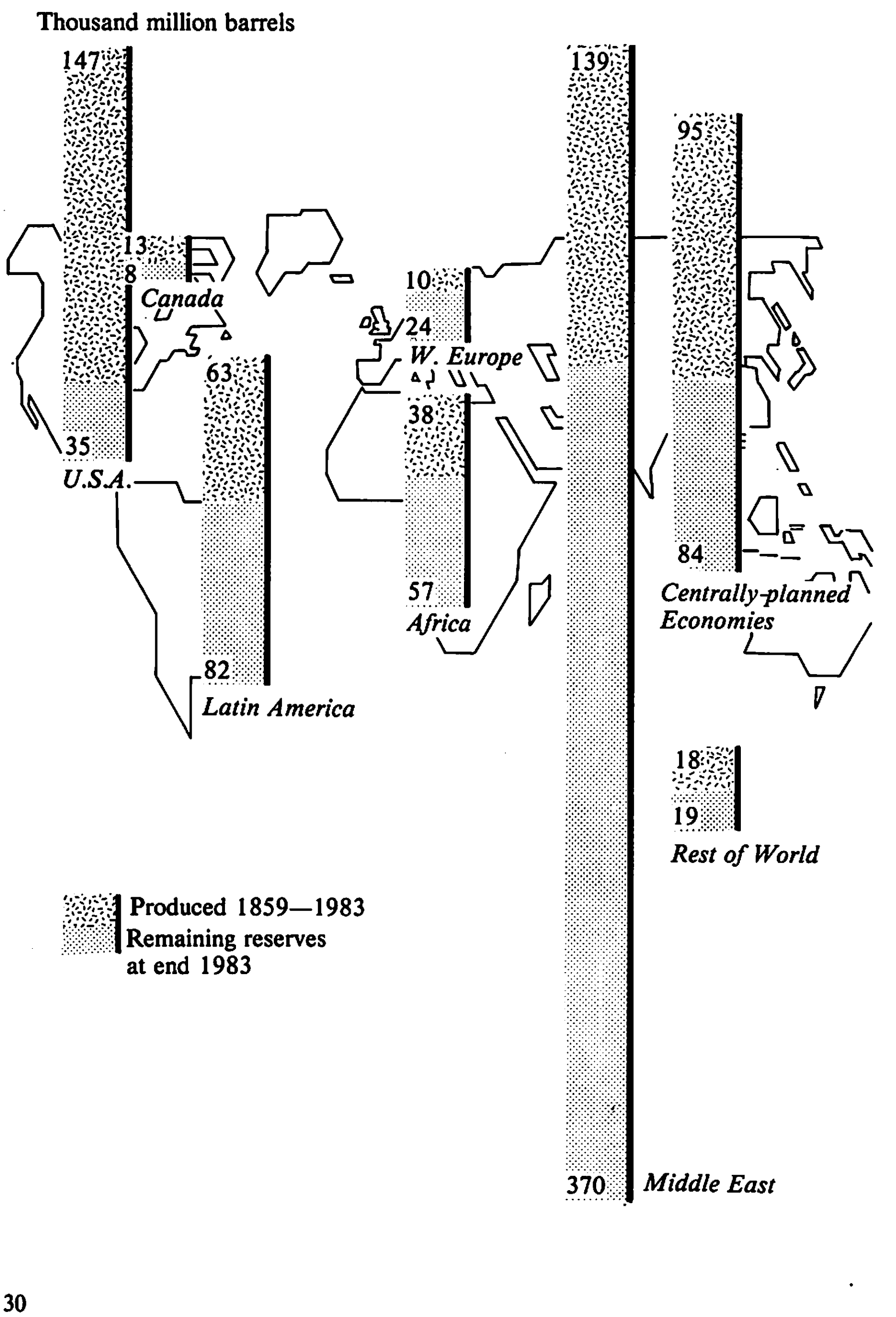
In the UK in recent years, the fall in oil consumption has been due to a decline in the use of gas oil and heavy fuel oil in industry and electricity generation. This has meant that refiners have had to change the proportion of their output by closing down some refineries and installing catalytic crackers, etc in the remaining refineries to upgrade residual oil to transport fuels. Note that in the USA, the market has traditionally been much more biased towards transport fuels, especially petrol. In the UK we still have a long way to go before we match their capacity for upgrading residual oil.

Table 2 Shape of the Refinery Barrel

Product type	*'Straight run' Arabian Light, %*	*Refinery yield, %* UK 1972	UK 1983	USA 1972	USA 1983
Light	16	21	34	46	50
Middle	38	32	28	31	30
Residual	46	47	38	23	20
Total	100	100	100	100	100

Sources: BP (1984), Department of Energy (1984), Skinner (1983).

Fig 5 Oil discovered 1859–1983 (Source: BP Statistical Review of World Energy)



Complete upgrading of residual oil to transport fuel is possible, and it is likely that as crude oil becomes more scarce and expensive, it will increasingly be used for premium applications, while non-premium uses such as steam-raising and electricity generation will depend more on coal and nuclear power.

Unconventional oil sources

There are very large deposits of unconventional oil sources, such as the very heavy crude oil in the Orinoco region of Venezuela, the Athabasca tar sands in Canada and the oil shales of the Piceance Basin of Colorado. It is estimated (World Energy Conference 1983) that the recoverable oil from these resources could be about 80–90 billion tonnes, which is about the same as proven reserves of conventional oil (92 billion tonnes). However, it is much more expensive to extract unconventional oil reserves. For example, heavy crude oil has to be extracted by injecting about 6 kg of steam for every kg of heavy oil produced. In the case of oil from shale, it takes 10 tonnes of shale to be mined and processed at ~500°C to extract one tonne of oil. In both cases, the initial product is similar to residual fuel oil and requires considerable upgrading to produce a premium transport fuel.

Coal liquefaction

Coal reserves are much more plentiful than oil reserves. According to a survey carried out by the World Energy Conference in 1980 (World

Energy Conference 1983), the global proven recoverable reserves are 728 billion tonnes, which on an energy equivalent basis is about 5 times the total oil reserves. There are a number of different processes available for converting coal to synthetic petrol. In fact, during World War II, Germany had about 12 plants producing around 3 million tonnes of fuel per year. In South Africa, which has difficulties in obtaining secure oil supplies, there are 3 plants currently operating.

Coal liquefaction is an expensive option, however, and will only be cost-effective if coal is cheap relative to oil. The liquefaction process is at best about 60% thermally efficient, and there is a high capital and operating charge for the process plant. Thus for coal at £1.50/GJ (ie £42/tonne, which is about the lowest price which can be envisaged for coal produced in Europe), the cost of producing synthetic petrol is about £7/GJ, compared with a current spot market price of petrol of about £4.1/GJ (excluding tax). In order for coal liquefaction to become economic in Europe, the price of oil would have to double relative to coal. Given the high production costs of European coal and the large reserves of unconventional oil resources and cheap coal overseas, for example in Australia, it is unlikely that European coal will be a cost-effective source of synthetic petrol for the foreseeable future.

Natural gas

Natural gas can be used directly as a fuel for transport by storing it in pressure cylinders. In New Zealand, where there are large reserves of natural gas but virtually no oil, there are now a substantial number of cars running on CNG (compressed natural gas). Natural gas is in fact a very good fuel for internal combustion engines. However, the size and weight of the pressure cylinders is a serious disadvantage for the private car user, and it requires a considerable price advantage to encourage its use. For agricultural vehicles, the inconvenience of pressure cylinders would perhaps be less of a disadvantage.

Natural gas can be readily converted into methanol, which is a liquid and therefore more easily stored. There are many proponents of the direct use of methanol as a fuel, although it does have certain disadvantages. Its volumetric energy density is only half that of petrol, so 2 gallons of methanol are required to substitute for one gallon of petrol. Mixtures of up to 10% methanol in petrol can be used in unmodified engines, but for higher methanol content, substantial redesign of the engine would be required.

It might be more practical to convert the methanol, whether from natural gas or any other source, to synthetic petrol. Mobil have developed a catalytic route for this conversion, using a special zeolite catalyst, and the first commercial plant is under construction in New Zealand.

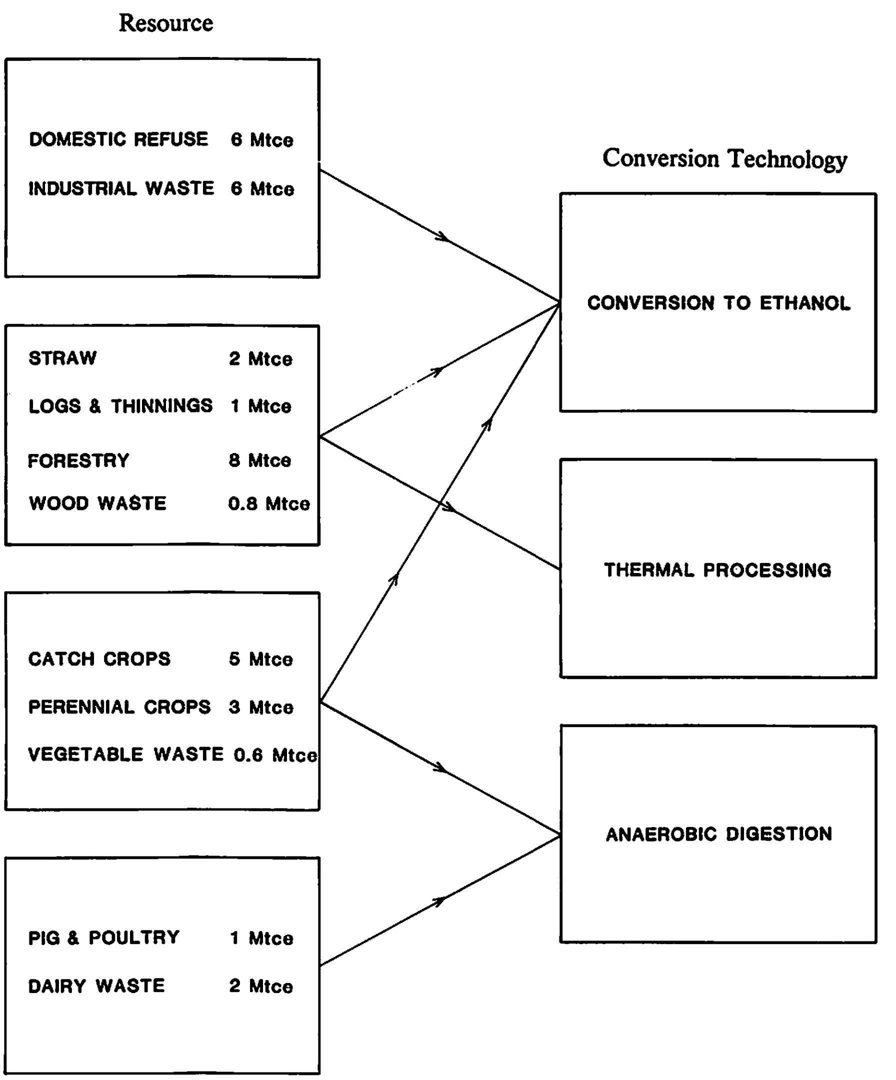
In Europe, the prospects for using natural gas, or a synthetic fuel derived from it, depend on the price and availability of the natural gas. At present the size of North Sea gas reserves, although adequate for many years at present consumption rates, would not justify any major development of them for transport fuel applications. However, supplies of natural gas from the very large reserves in Siberia and the Middle East may make a contribution to the global synthetic fuel market in the early years of the next century.

In the long run, all fossil sources of energy are exhaustible, and although reserves of conventional oil can be greatly extended by turning to other fossil sources, eventually these too must become depleted and we will have to turn to a renewable source. Biomass is a renewable energy source which agriculture is uniquely placed to exploit.

Fuels from biomass

The agricultural industry is already in the business of producing 'biomass', both animal and vegetable, for use primarily as foodstuff. However, in the future there will be an increasing potential for using waste materials, and even specially grown crops as the raw

Fig 6 Estimated Quantities of Biomass available in the UK (Ref 5)



materials in the production of fuels (ETSU, 1982).

Gaseous fuels, such as methane, may be produced from animal and vegetable wastes, or cultivated crops by anaerobic digestion, and thermal processing. Liquid fuels may also be produced by the thermal processing of woody biomass, fermentation of sugars and starch or treatment of high cellulose materials. The estimated resource size for such fuels in the United Kingdom is shown in figure 6.

Anaerobic digestion is perhaps of most immediate interest as the basic technology is already well developed, it can be carried out on any scale from the individual farm to large centralised complexes serving a number of farms or industrial installations, and offers additional advantages as a method of waste treatment should future environmental regulations require it. However, in order that the fuel produced might be used to provide motive power in the field, some development in engine design will be necessary.

Thermal processing, which will be described in more technical detail below, requires more advanced technology, whose complexity and economies of scale require that it should be carried out in large installations. However, the agricultural industry may well be heavily involved in providing feedstocks for such operations at the beginning of the next century, as well as using the fuels thus produced.

Fermentation of sugars and starch is an established technology, familiar to any home wine-maker or brewer, and has already been widely practised for fuel production in other countries — most notably Brazil. It is also possible to produce ethanol in a similar way from high cellulose materials.

Anaerobic digestion of organic materials to produce fuel gases

Micro-organisms grow in an aqueous medium of organic material, using it as their source of energy. During this process the chemical structure of the waste material is broken down and a mixture of gases is released, comprising carbon dioxide (~30%) and methane (~70%), with traces of hydrogen sulphide. The waste materials are collected in specially designed tanks, or digesters, which exclude air from the reactants (anaerobic) and contain the gases produced. The thermal content of the biogas depends upon the specific proportions of its constituents and generally has about three quarters of the thermal value of natural gas (ie ~26 MJ/m^3 compared with 36 MJ/m^3 for synthetic natural gas).

The gas produced may be cleaned of the hydrogen sulphide and carbon dioxide, and the remaining methane pressurised and bottled for use. This is already being done by certain Local Authorities who use surplus sewage gas to provide motive power for Authority vehicles.

Anaerobic digestion is a technically simple process requiring relatively straightforward plant, although the biological processes involved are complex and not well understood. It is especially suited to the treatment of organic materials which have a high water content such as animal wastes, plant and vegetable materials. Digesters are commercially available in the UK and on the Continent as a means of pollution control and waste disposal and work is currently underway to optimise their operation for fuel production.

Digesters could range in size from single farm units of around 12 m^3 up to installations of 20,000 m^3. Feedstock requirements in terms of cattle waste would be equivalent to 64 head of cattle for a small 30 m^3 plant and 10,000 head for a 5,000 m^3 digester. In terms of green plants, the equivalent plantation area would be ~ 6½ hectares for 30 m^3 and 1,100 hectares for 5,000 m^3 digesters.

One advantage of anaerobic digestion is that the sludge remaining after the waste has been processed, can be used as a fertiliser, and contains a similar amount of plant nutrient to the raw animal waste. It may also be used as an animal feed supplement, being rich in protein.

A variety of factors remain to be resolved concerning anaerobic digestion. Work is in hand to demonstrate that existing prototype digesters can achieve their design performance over sustained periods, to improve the rate of digestion and degree of control which can be exercised over the gas output.

It is also important that digesters should be able to operate with a range of feedstocks, to maintain flexibility in agricultural practice. Digestion of dairy wastes is a less efficient process than the digestion of other animal wastes and long retention times in the digester are necessary.

The values of all feedstocks for anaerobic digestion mainly depend upon 4 factors:

- the price of conventional fuels, and hence the value fuel savings;
- the capital cost of digester installations, and the discount rate applied to the investment;
- the value of solid residues which may be sold as fertiliser or animal feed;
- the cost of supplying feedstocks.

Increasing fuel costs in the future will encourage the farmer to consider a range of alternative fuels, and the economic options available to him will be determined by the nature of his operations — whether arable or pastoral — and his approach to technologies previously outside the realms of conventional farming interests.

Thermal processing of biomass to produce liquid fuels

The technology required in this process is similar to that used in coal gasification: the feedstock is heated in a controlled atmosphere of oxygen or steam and a mixture of gases (carbon monoxide, carbon dioxide, hydrogen and methane) is produced. This may be further processed to substitute natural gas or liquid hydrocarbons.

Such a plant producing 500 tonnes of methanol per day would require about 1,000 dry tonnes of feedstock per day, grown on around 47,000 hectares of land. In view of the complexity of the technology and the available economies of scale, it is envisaged that fairly large installations should be established, with the optimum plant size being dictated by the availability of feedstocks and the logistics of collection and delivery to the processing plant.

There is currently some uncertainty surrounding the technology and economics of thermal processing to produce liquid fuels, and most of the available evidence relates to coal gasification and liquefaction processes. However, this technology has the potential to develop over roughly the same timescale as the coal processing technologies described in the first part of this paper.

Apart from technological uncertainties, one of the most important factors in estimating the future potential for producing liquid fuels by this route is uncertainty in the long-term supply of feedstock, the most appropriate being wood. Supplies are relatively inelastic in the short-term, with long lead times for planting and harvesting, and in the long-term the scale of operation which may be required could be environmentally unacceptable. However, it may be possible to establish sufficient supplies of wood-waste and forestry thinnings to satisfy demand.

The precise nature of the fuel which might be supplied will be determined by future fuel prices and relativities, and developments in engine design. The direct use of methanol and its conversion to synthetic petrol have already been discussed in the previous section of this paper.

Production of ethanol

Ethanol, like methanol, can be used as a fuel in internal combustion engines either in a 10–20% volume blend with gasoline, or as a neat fuel. Although it cannot be used neat in diesel engines, in view of its high octane quality and low cetane number, it may be used as a supplementary fuel by separated injection of the 2 fuels into the engine, or by producing emulsions of ethanol in diesel fuel.

The best known Government initiative in fuel alcohol production is that of Brazil, which launched its national alcohol programme in 1975. The target production is 10,700 million litres of ethanol per year by 1985, 90% produced from sugar cane and 10% from cassava (World Energy Conference 1983). It is estimated that this will require 4.6 million hectares of cultivated land, but Brazil has vast areas of land in excess of that required for food production.

Ethanol is produced by the fermentation of sugars and starch derived from crops such as sugar cane, cassava and cereals. However, the overall economics of the process vary markedly from one feedstock to another: most have an opportunity cost as foodstuffs, and the process efficiency and product yield are both feedstock dependent. The opportunity for this kind of operation in the UK or Europe is limited to surplus sugar beet or spoiled grain, and the impact such resources could make on our fuel requirements is trivial.

However, the feedstock offering a potential for ethanol production in Europe is cellulose, in the form of industrial and domestic refuse, agricultural residues such as straw, waste paper and wood waste. These materials are readily available, cheap and have no value as foodstuffs. However, the micro-organisms which metabolise sugar and starch cannot use cellulose as a feedstock, but organisms which will act on cellulose are known and research and development work is underway to exploit this resource for fuel production.

A variety of methods exist for hydrolysing cellulose to fermentable sugars: this can be achieved by high-temperature dilute acid treatment, low-temperature concentrated acid treatment, enzymic hydrolysis, and research and development work is being carried out on all the processes in an attempt to bring them to commercial viability.

Vegetable oil as fuel

The use of vegetable oils for fuelling diesel engines is not a new idea — Rudolph Diesel's first engine ran on such a fuel — although their use has so far been limited to laboratory conditions. Work has only recently begun to evaluate the performance of commercial engines operation on these fuels.

The viscosity of vegetable oil is approximately 10 times that of conventional diesel fuel, and cloud and solidification points are much higher, although this may be resolved by diluting the oil with diesel fuel or by further chemical processing. Problems may also occur with engine lubrication, but the ignition characteristics of engines run on vegetable oils appear to be acceptable.

In the Philippines, surplus coconut oil is already added to all diesel fuel at 5% concentration, and other countries have shown interest in using soya, palm, sunflower, peanut, cotton seed and rape seed oils. These fuels are currently more expensive than conventional diesel fuel, and although they have for many years been recognised as suitable for use in such engines there remain several technical difficulties which must be overcome, before they can be accepted for widespread use in commercial vehicles.

At the beginning of the next century the agricultural industry might be involved not only in using fuels from non-conventional sources, but also in supplying the feedstocks for the production of such fuels.

The nature of these fuels will depend on a variety of factors including:

- future fuel prices and fuel price relativities;
- the success of R&D work currently in progress to bring alternative fuel technologies to the point of commercial viability;
- the establishment of feedstock

resources and a reliable supply chain;
— the willingness of fuel users and engine designers to work with new fuels from unconventional sources.

Present estimates of the production cost of a range of biofuels are shown in table 3, where they are compared with the current price of conventional fuels. This shows that at current fuel prices the production of certain biofuels is uneconomic, but an increase in the price of conventional fuels as discussed in the first part of this paper could make the use of these renewable resources economically attractive.

Table 3 Estimated production cost of biofuels compared with the price of conventional fuels

Biofuel	*Production cost*	*Conventional fuel*	*Price*
Biogas	£3–13/GJ (excluding sale of residue)	Pipeline gas	£3.19/GJ
(Plant operating to manufacturer's specification — cost dependent on plant size)	£0–9/GJ (including sale of residue)		
Methanol — wood feedstock	~£170/tonne	Methanol — chemical feestock	~£120/tonne
Ethanol — feedstock wood waste (Europe)	~ $368/tonne*	Ethanol — chemical feedstock	NA †
Sugar beet & green crops (Europe)	~ $441/tonne*		
Maize (USA)	~ $367/tonne*		
Sugar can (Brazil)	~ $372/tonne*		

*Martin, 1982 †NA = Not Available

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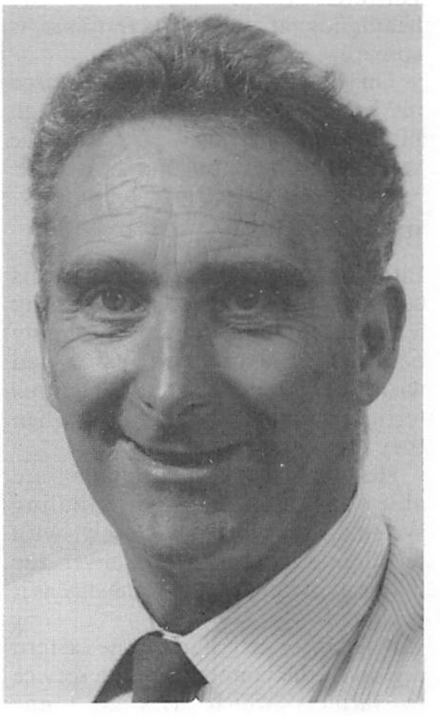
Developments in the handling and application of solid fertilisers

D A Bull

Summary

METHODS of handling solid fertilisers are reviewed, factors influencing fertiliser spreading performance are discussed and the types of application machinery are described together with comments on the assessment of distribution patterns.



Introduction

THIS article reviews developments in the handling and application of solid fertilisers which have taken place since 1968 when Mr T L Green presented a paper to a National Meeting of the Institution entitled "Achieving the distribution requirements for solid fertilisers" (Green 1968).

In the intervening years, the quantities of solid fertiliser used in British agriculture have increased, in line with the higher yields now obtained from farm crops; at the same time, the number of persons employed in agriculture has decreased.

A noticeable trend in recent years has been the interest shown by fertiliser manufacturers and by suppliers of fertiliser handling and application machinery in providing an integrated service for farmers who purchase their products. For instance, fertiliser manufacturers now offer the customer not only a range of compounds but a choice of handling package and they advise on handling methods.

Fifty kilogram bags

Most of the fertilisers used in this country are handled in 50 kg polythene bags and these are transported from factories to depots located throughout the country in palletised units of 30 bags (1.5 tonnes). More recently, the palletised bags have been available protected by a shrink wrapped polythene sheet. The sheet has two functions, one to make the pallet load more stable, the other to protect the contents from the weather.

Not all farms are equipped to handle 1.5 tonne pallets, in which case a pallet load less than 1.5 tonnes might be delivered to the farm, or the bags are manhandled. Even when 50 kg bags are palletised, their final emptying movement is by hand.

On the majority of holdings, pallets are moved by tractor mounted equipment such as front end loaders fitted with pallet forks or rear mounted fork lift masts. An increasing number of specialised loaders, including rough terrain fork lift trucks, telescopic loaders, industrial shovels and second-hand fork lift trucks, are also used on farms. Most specialised loaders are capable of handling 1.5 tonnes.

An alternative to handling fertiliser in 50 kg bags is to use flexible intermediate bulk containers or "big bags" as they are more commonly known.

"Big bags"

"Big bags" have been used for handling fertiliser in this country since the early 1970s and they are now available in ½ tonne, ¾ tonne and 1 tonne packages.

"Big bags" consist of an outer cover made from woven polypropylene and a polythene liner. Most are designed to be handled by a crane hook. Some "big bags" are lifted from loops of webbing at each corner whereas others use the side panels of the bag itself as the lifting medium. It is usual to stack the bags two high inside buildings and adequate clearance should be allowed for the crane hook.

Quite recently, a manufacturer introduced a "big bag" for handling fertiliser which incorporates a disposable wooden pallet base. These bags hold ¾ tonne of fertiliser and they can be stacked six high using fork lift equipment (fig 1).

"Big bags" are emptied either through a spout which can be tied off or, more usually, the bottom panel and the liner are severed to allow the contents to flow out.

Handling equipment must provide sufficient lift height to raise the bag above the spreader hopper and it is an advantage if the hopper holds more than the quantity of fertiliser in the bag so that the contents can be emptied in one shot.

Equipment which is used for lifting "big bags" includes simple hook attachments for fitting to tractor front end loaders, tractor mounted cranes which work in conjunction with tractor mounted spreaders and slewing jibs fitted to flat bed trailers.

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No manual lifting is required when fertiliser is handled in "big bags" and this is a real advantage for the operators, especially when large areas are being fertilised at high application rates.

Reducing the time spent filling the spreader hopper is one means of increasing the area spread in a day. However, some farmers consider it a disadvantage to carry the extra weight of cranes or to have handling vehicles travelling about the headlands at the time fertiliser is spread.

On some farms, fertiliser delivered in "big bags" is discharged into high lift or dumper trailers to enable the spreader to be re-filled at a fast rate.

Bulk

Little progress has been made in this country with methods of storing fertiliser in bulk. This is probably because of the difficulties associated with keeping high nitrogenous fertilisers in good condition when they are stored in a heap.

However, some contractors are able to operate bulk handling systems by working closely with fertiliser suppliers who deliver the material in bulk on the same day as it is spread.

A fertiliser merchant in the eastern region of the country offers a service to farmers which uses 20 tonne capacity, fibreglass, self-standing hoppers. These hoppers are filled with fertiliser from bulk lorries, equipped with pneumatic blowers. Filling a spreader from a self-standing hopper is quick and easy, although there is the disadvantage that more time than usual may be spent by the spreader travelling to and from the supply hopper.

Factors influencing performance

In addition to the time spent by the spreader travelling and being filled, other factors which influence the area spread in a day include the application rate (kg/ha), forward speed and bout width.

The travel speed when spreading fertiliser has remained at about 2.6 m/s (6 mph) but there has been a significant increase in the bout widths used on farms. In 1968, the effective working width for the majority of spreaders was 6 metres, whereas 12 metres is more common today. The trend to wider bouts has been influenced by the introduction of tramlines in cereal production systems. It is interesting to note that some arable farmers have now adopted 18 metre or even 24 metre tramline systems.

Fig 1 A recently introduced method of handling fertiliser which uses a disposable pallet [ICI Agricultural Division photograph]

Application machinery

There are three types of fertiliser spreader in use, namely spinning disc (1 or 2 discs), oscillating spout, and pneumatic (full width). These machines are available for mounting on tractor 3 point linkages or for use as trailed machines and prices range from £300 to £11,00.

Spinning disc and oscillating spout spreaders produce a triangular distribution pattern and the width of spread is overlapped to obtain an even distribution across the field. Pneumatic machines, on the other hand, are operated with no overlap.

The spreading mechanisms on spinning disc and oscillating spout spreaders have not changed greatly over the years, although there have been improvements in details of design and in the materials used in their construction.

The first pneumatic fertiliser spreaders operated in the United Kingdom were imported from Europe. They work in such a way that fertiliser is metered from the hopper into individual tubes, through which a stream of air is passing. These tubes of unequal length terminate in outlets equally spaced along the boom, and on leaving these, the fertiliser meets spreading plates which distribute the granules evenly over the ground surface (fig 2). On some machines, the spreading plate is fixed; on

Fig 2 A trailed 12 metre pneumatic fertiliser spreader [AC Bamlett Ltd photograph]

others, it is a rotating component driven by the air stream.

Whichever type of machine is chosen, the user expects it to be reliable, straightforward to operate and supplied with an instruction book which is easy to understand.

The use of more powerful tractors on farms provides the opportunity to carry heavier loads or to pull larger trailed equipment. This includes the use of heavier fertiliser spreading machinery (hoppers to 7 tonnes capacity) but there has been an understandable reluctance on the part of some operators to use large spreaders, since these result in increased weight travelling over the land at times of the year when the soil is easily compacted. This is one reason why some tractors and self propelled vehicles which are used for spreading fertiliser are now equipped with low ground pressure tyres.

Accuracy

The standards required in the accuracy of distribution have not changed since 1968 and, to quote from Green's paper, "machines should be capable of applying fertilisers to the agronomic standards so that the coefficient of variation of the application rate does not exceed 10% on high value crops and 15% on low value crops".

This standard of accuracy may not be difficult to achieve with new machines working under test conditions but, under farm conditions, it calls for attention to details. Details such as:—

(i) keeping the machine clean and in good mechanical condition;
(ii) running the power-take-off at the correct speed and setting the spreading mechanism at the recommended height above the ground or crop;
(iii) driving accurately;
(iv) using good quality fertiliser.

Compared to indoor test conditions, factors which cause problems in practice and which are difficult to avoid, include high relative humidity, crosswinds and sloping fields.

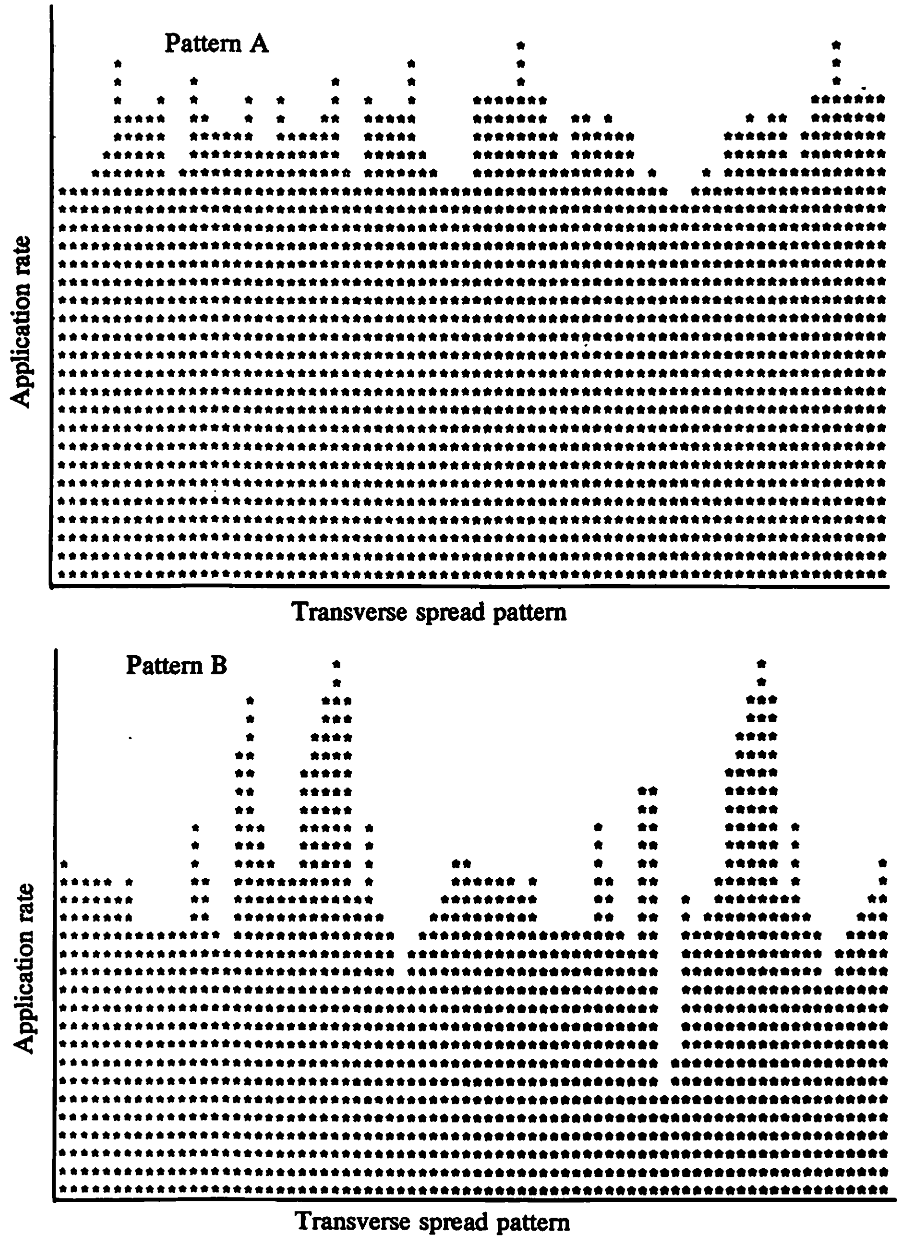
The major fertiliser manufacturers offer an on-farm spreader calibration service and they also carry out development work in conjunction with the manufacturers and importers of fertiliser spreading machinery. There is also a British Standard (B.S. 6483 Part 1) which defines test procedures.

In his paper, Green was able to refer to the NIAE Test Reports including two Series Tests of fertiliser application machinery. These reports gave details about the quality of work, rate of work, ease of operation and machine construction (NIAE 1964). Unfortunately, these tests have been discontinued in the United Kingdom so potential customers have to rely on manufacturers' literature, other users' experiences and the Agricultural Development and Advisory Service for information about machine performance.

ADAS study

In 1980, the ADAS Mechanisation Department issued a report on a national study of the handling and application of granular fertilisers (MAFF 1981). This report is based on a study of 177 machines, including 18 different makes. The evenness of fertiliser application from each machine was assessed during normal field operations. A computer program was used to calculate the coefficient of variation for each assessment and a computer print-out which showed the distribution pattern helped in advising the farmer about the machine's performance (fig 3). Samples of fertiliser were taken and analysed to determine its bulk density and mean particle size.

Fig 3 Computer print-outs showing the transverse fertiliser distribution patterns recorded on two farms which were using the same make of 12 metre pneumatic spreader but producing a good and a bad result:
pattern A – coefficient of variation = 10%
pattern B – coefficient of variation = 24%
[NIAE photographs]



Results showed that the evenness of spread was outside normally accepted limits from half the machines assessed, although the report concluded that one fifth of the machines performed to a high standard, indicating that most fertiliser spreaders are capable of acceptable work if they are well maintained and operated correctly.

In general, the fertiliser quality was good and did not appear to adversely affect distribution patterns.

There was a wide range in the rates at which fertiliser spreader hoppers were filled, depending mainly on the ability and enthusiasm of the operators.

Conclusions

Developments in the handling and application of solid fertilisers rely on good co-operation between fertiliser manufacturers, merchants, agricultural engineers and farmers.

There is a wide range of fertiliser application machinery available. Most machines are capable of an acceptable standard of work provided that they are operated with skill.

As farmers look for alternatives to handling fertiliser in 50 kg bags there appears to be increasing interest in the use of "big bags" but a disadvantage of handling fertiliser in this way is the extra weight of lifting tackle which, if used in the field, might result in soil damage due to compaction.

Since most farms are equipped with some form of loader bucket there may be a case for further developments to do with handling solid fertilisers in bulk.

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South of Scotland Electricity Board activities in wind energy

J C Waterton

1 Background

COMPARED with other parts of the United Kingdom, the prospects for the beneficial development of wind energy in the south of Scotland are probably above average, although wind conditions do not ordinarily match those found further north and west, and there are no isolated areas where the normal electricity supply is from relatively expensive diesel generation.

When the widespread examination, or in some cases re-examination, of renewable energy sources got underway in the mid and late' 70s, interest first turned to the use of hilltop sites for wind energy. Certainly, the south of Scotland is quite well endowed from that standpoint. At that stage in the proceedings, the South of Scotland Electricity Board (SSEB), who were actively involved in the early design studies on the UK 60 m, 3.7 MW wind turbine, were offering to host the prototype machine on a site at Bennan Hill, on the coast a few miles south of Ayr, and appropriately enough just above the well known Electric Brae. In the autumn of 1980 however, a decision to use the site at Burgar Hill in Orkney was taken, and the direct participation of the SSEB in the UK large machine programme was interrupted. The Board nevertheless remain interested in the outcome of the project and, as it proceeds, we shall continue to review the economics of large machines on our system.

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2 Evolution of SSEB policy on wind energy

The present policy of the SSEB on wind energy crystallised some two years ago. On a UK basis, it appeared to us that large, MW-size machine developments were being adequately underpinned by the programmes with which the North of Scotland Hydro-Electric Board and the Central Electricity Generating Board were associated, and it would be more useful for us to look in other directions.

The use of wind turbines in agricultural applications, and perhaps also small industrial applications, was a potentially promising area for investigation. Looking at wind turbine economics for a fairly large farm and, more importantly, a fairly high electricity consumption, there could well be a nucleus of practical instances in the SSEB supply area where a wind turbine in the size range up to 50/60 kW might be a modestly attractive private investment. There were some fairly large uncertainties in this assessment, but after making calculations for what we considered good but not exceptional combinations of wind and load regimes, we found outselves predicting payback periods of 8–10 years (after taking possible grant aid and tax savings into account), and corresponding internal rates of return of 5–8%, provided a machine life of 15–20 years could be reliably obtained. Table 1 is an abstract from an internal policy paper produced early in 1983. A 22½% investment grant was assumed to be available under the Agriculture and Horticulture Grant Scheme, as it was being applied at that time, and we based our estimates of wind turbine output on an annual mean wind speed of 5.8 m/s at hub height.

The two nominal machine sizes were fairly arbitrarily selected, being chosen on the basis that the machine output over the year should be about one third of the farm demand which, in turn, we thought justified us in making the further assumption that 80–85% of the wind turbine output would typically be consumed on the premises, and only the remaining small proportion sold to the Board at times when wind turbine output exceeded farm demand. Incidentally, an assumption underlying this whole study was that the machine would be connected to the Board's distribution system, and that generators would be of the induction type.

It was in the light of the above economic calculations that a policy decision was taken to install two demonstration units of nominal 15 and 40 kW rating for evaluation purposes, in order to provide data which would enable SSEB to establish by actual trials, the operating characteristics of this type of machine over a period of a few or several years. As a Board, we would be interested in finding out whether there were likely to be any operational or environmental problems of which we should be aware, so that we would be well-informed, and able to take a lead in resolving any such problems satisfactorily if the private installation of wind turbines in agricultural or industrial applications were to grow over the coming years. The

Table 1 Economic appraisal of wind turbines for agricultural applications

Nominal machine rating, kW	*Rotor diameter, m*	*Machine output, kWh/annum*	*Matching farm consumption, kWh/annum*	*Farms in SSEB area exceeding stated consumption*	*Payback period, yr*	*Rate of return, %*		
						Economic life, yr		
						10	*15*	*20*
15	8	28,000	100,000	100–110	9.9	–	5.2	7.1
40	14	90,000	250,000	15–20	8.7	2.2	6.8	8.7

information from the demonstration should also be helpful in ensuring that our buy-back tariff is formulated fairly, taking properly into account the particular characteristics of surplus electricity from wind turbines.

We also felt that a demonstration programme might in itself trigger farmers and industrialists to consider the purchase and installation of their own machines, thus encouraging the small wind turbine market in general, and providing an opportunity for UK manufacturers.

3 Programme implementation

3.1 Site selection

Implementation of the Board's policy required suitable sites to be found for the two demonstration machines. We gave early consideration to the use of sites already in Board ownership, at or near power stations or transmission substations, but for various reasons these were less than ideal. What in retrospect seems obvious then struck us: what better than to approach the agricultural colleges and enlist their co-operation? In the event, our first machine (the smaller of the two) has been installed on a site at the West of Scotland Agricultural College, Auchincruive, near Ayr, and we are at present in the process of reaching agreement with the East of Scotland College of Agriculture on a site for the second machine at Easter Howgate, near Penicuik.

In this way, not only will the attention of the farming community be most actively directed towards the idea of wind turbines, but also, in due course, the dissemination of operating experience from the demonstration machines will be facilitated.

At the local level, we do not intend to site the machines within 150 m of occupied buldings. We have also aimed at choosing "open" sites with reasonable exposure from all wind directions. The sites are not intended to be outstandingly windy ones, but to be reasonably typical of the kind of site available on farms with fairly large electrical loads: in practice such farms are mainly in lowland areas, and we have therefore not looked specifically at hilltop siting.

3.2 15 kW machine progress

Enquiries for the first, smaller machine were issued by the Board in the middle of 1983, and a contract was placed with International Research and Development Co Ltd in March this year. The machine was erected in July and commissioned on 2 August. August must have been one of the most windless months on record, but the machine operated for long enough to confirm there were no significant operational or environmental problems, and we now await the first winter's experience.

The International Research and Development Co Ltd machine is of three-bladed, fixed pitch, upwind design, with tubular tower, and nacelle yaw control by fantails. Outline particulars are as follows:

design output and wind speed	15 kW at 11 m/s (25 mph)
cut-in wind speed	4–5 m/s (approx 10 mph)
maximum operating wind speed	30 m/s (67 mph)
rotor diameter	7.9 m (26 ft)
hub height	12.5 m (41 ft)
rotor speed	100 rev/min

The rotor drives a 3-phase, 415 V, induction generator through a step-up gear box and belt drive.

A tubular tower was preferred to the alternative of a lattice tower, as it provided a convenient and secure location for the machine control gear and also for the Board's monitoring equipment. In addition, it means that a stock fence is not required, and the idea of just 'sticking it in a corner of a field' is quite realistic.

3.3 40 kW machine progress

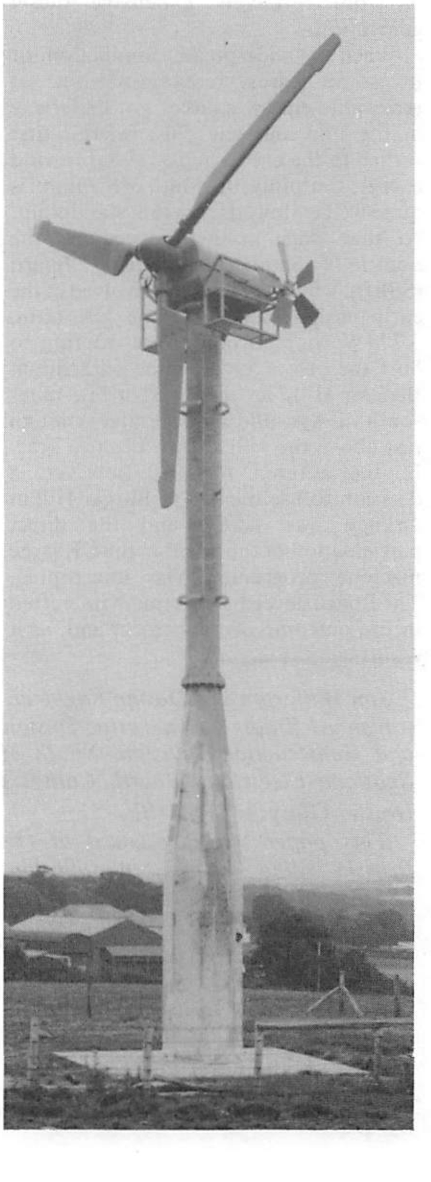
Enquiries for the second, larger machine of nominal 40 kW output were issued in April 1984, and we expect that a contract for this machine will be placed within the next few weeks. A diameter in the range 11–14 m was specified, but with provision that this might be increased to 15 m by agreement. This brings standard 55 or 60 kW machines as offered by a number of manufacturers within the range of possible options.

3.4 Monitoring

The Board's Technical Services Department will monitor the machines for whatever length of time appears justified, probably between two and five years. Monitoring is basically for performance calculation purposes, and consists of wind speed and direction data (obtained from instruments mounted at approximately hub height on a separate anemometer tower), together with export and (separately) import kWh and input kVArh. Information is recorded on tape, together with other status data extracted from the machine control and protection system. Structural monitoring of the machines is not proposed.

One aspect of performance which is not at present being monitored, but which may be included in the future, is the integration of wind turbine generation with the local farming load, and the

Fig 1 The 15kW wind turbine owned and operated by the South of Scotland Electricity Board, on a site provided by the West of Scotland Agricultural College, Auchincruive, Ayr; machine designed, constructed and erected by International Research and Development Co Ltd, Newcastle upon Tyne.



possible reoptimisation and management of the load demand pattern to match the actual generating pattern of the wind turbine, so increasing the proportion of electricity used on-site, and reducing buy-back.

4 Concluding remarks

In focusing on the possible use of small wind turbines in agricultural applications, the SSEB believes it has identified a part of a wind energy field which is suited to the natural characteristics of the south of Scotland, has potential for development, and has not so far been investigated in depth by others. The Board's demonstration programme of two wind turbines of nominally 15 and 40 kW is well in hand, and the first results are now coming in. It is too early to draw firm generalised conclusions, but a recent update of the studies on which the Board's original policy decisions were based, allows an educated guess to be hazarded that the economics of wind turbines are now sufficiently attractive to encourage private installation in favourable cases.

The experience of the south of Scotland Electricity Board with its own machines will allow it to react in an informed and responsive manner to enquiries from prospective private generators who are interested in operating in parallel with the Board's system, and should help to ensure that no unnecessary difficulties are placed in the way of future wind turbine installations.

5 Authors' addendum, November 1984

Since September when the Scottish Wind Energy Workshop took place, the Auchincruive machine, shown in the illustration, has begun to accumulate running hours quite quickly, and its behaviour has been very encouraging.

The SSEB has also now placed a contract with James Howden & Co. for a 60 kW wind turbine for the East of Scotland project, and this is expected to enter service in Spring 1985. This machine will have a 15 m diameter, 3-bladed rotor on a 20 m hinged mast. The proposed site has been moved a few 100 metres to Castlelaw Farm, and a planning application has been submitted.