BRIQUETTING OF AGRICULTURAL WASTE FOR FUEL

Introduction

The realisation that deforestation and woodfuel shortages are likely to become pressing problems in many countries has turned attention to other types of biomass fuel. Agricultural residues are, in principle, one of the most important of these. They arise in large volumes and in the rural areas which are often subject to some of the worst pressures of wood shortage.

However, residues are often bulky and difficult to burn so various conversion techniques have been developed. One of the oldest of these is briquetting which has been used in Europe since the 19th century to make fuel from low-grade peat and brown coals.

The use of briquetting for conversion of agricultural residues is comparatively recent, however, and has only been taken up in developing countries in the last ten years.

The experience of briquetting agricultural residues has been mixed. Various technical problems have been encountered but the main difficulty has been the fact that, in many places, briquettes are too high in cost to compete with existing woodfuel. However, in some countries, a briquetting industry has begun to develop and find its market niche.

The world-wide experience of briquetting plants is not well-known, either in success or failure. In 1987, the Swedish International Development Agency (SIDA) financed a study of briquetting on a case study basis as well as to review technology and general economics. This report is the result of that study.

The general conclusions presented here are that briquetting plants require some particular circumstances to be successful. There have been more failures than successes throughout the world because of over-optimism about the economic competitiveness of briquetting.

However, in the right circumstances, briquetting plants can make a useful contribution to fuel supply and can be commercially successful. We hope that this report will help to guide people interested in the utilisation of agricultural residues towards the right choices of technology and location and to improve the chances of successful briquetting. We give a list of acknowledgements of people who have helped with the project in Appendix I. We would like to emphasise here the thanks due to SIDA for providing the financial support necessary for the work.

Part 1.An overview of briquetting

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Chapter 1.Main issues

In this part we want to address the main issues of briquetting without going into detail of later chapters. These issues are conveniently contained under four broad headings:

- the residue base
- the market for briquettes
- the technology of briquetting
- its economics.

A discussion of technology and associated matters, such as operational and capital costs and the characteristics of the briquettes made by various techniques, sometimes dominates a study of briquetting. Yet in looking at the overall picture such a concentration may be misleading

Briquetting can be regarded as an attempt to link up two large and complex worlds: that of agriculture and that of fuel supply and use. Briquetting will never have the impact of a major new fuel such as oil, which can change entire patterns of consumer behaviour in the energy world, nor will it ever become the equivalent of an important new crop in agriculture. This means that the technology of briquetting must fit in with the existing agricultural context rather than the other way round.

This is a problem faced by many attempts to utilise natural resources in a way which is less wasteful. It is often convenient to divide human needs into neat compartments and then to provide for these needs in separate ways. But the price of convenience is often waste. It is usually necessary to examine the issues involved from a number of angles, not just technological, if ways to provide sustainable resource use are to be found.

First, we look at the residue base from which briquetting draws its raw material and consider the general circumstances in which briquetting might become established drawing upon particular types of residue. Then we look at the fuel markets in which briquettes might be used and how the nature of those markets effects the briquetting process.

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We then summarise the technology in terms of its technical features and its costs. Finally, we try to make some generalizations about the total cost of briquettes in different circumstances and how these costs compare with alternative fuels. In Parts 2 and 4, the technology and its economics are considered in much greater detail Here we are concerned to place the technology into a wider context to give some idea as to what role briquetting might play in fuel supply in developing countries.

Chapter 2.The residue base

Biomass densification means the use of some form of mechanical pressure to reduce the volume of vegetable matter and its conversion to a solid form which is easier to handle and store than the original material. There are a number of different densification techniques, which will be discussed in some detail later on; for convenience, they will all be called "briquetting" although, as will be discussed, they may produce final products which are very different.

The briquetting of agro-residues is one of a number of ways which have been developed to solve a problem: how to put the huge volume of wastes from agriculture and agro-processing to some useful purpose. (This presupposes, of course, that disposal of agro-residues is a problem. In fact, in many places, no such problem exists and residues are already absorbed in the local economy in a useful way). We are concerned with only one aspect of briquetting: its use for fuel production. Other applications of briquetting include the production of animal feed and, in general, any reduction of material volume to reduce transport of handling costs.

In aggregate, the numbers look very attractive. There is certainly a huge volume of residues which are associated with agriculture and with wood processing and, probably, most of these are not fully utilised. One of the major world crops, rice, has about 25% of the crop in the form of husk which amounts to about 100 million tonnes of residue. On a smaller scale, world production of groundnuts is about 10 million tonnes of which about 45% is shell. In general although there are crops with both higher and lower residue yields, it is reasonable to assume that about 25% of any dry agricultural feedstock is a residue.

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Barnard and Kristoferson (Barnard&Kristoferson, 1985) have surveyed the whole field of agro-residues and whilst wide variations exist between crops, they show that commonly between 1 and 2 tonnes of residue will arise from every tonne of cereal crops. Other crops produce residue ratios which are both higher and lower.

The actual volume of residues which arise in any place will depend upon the cropping patterns and yields in use. There are such big variations in these that any generalization is impossible. However, even in the most under-developed agricultural area, it is possible to produce aggregate numbers which are impressive. In Figure 1, we reproduce a calculation of Barnard and Kristoferson which shows the per capita residue production from cereal crops alone in various countries.

Table 1: Agricultural Residues in the Sudan (1978/79)

The residues concerned will have an average heat content of 12-20 GJ/tonne. This means that even in the least productive countries and including only cereal crops, it is possible, in theory, to envisage household fuel needs being satisfied very largely from residues in some form or other. As residues in rural areas arise close to the communities, the existence of such a resource-base has aroused hopes that a fuller use of agroresidues could provide a partial solution to fuelwood shortages and increasing fuel costs.

In Table 1, an estimate made for the fuel value of residues in one country, the Sudan, is shown. It can be seen from this that, in principle, the utilisation of residues could have an appreciable impact in a country which is suffering badly from fuelwood shortages.

The potential for utilisation of woodwastes is also, in principle, very great though there are no good data on the general arisings of such wastes. However, one survey has suggested that in 1979, worldwide, *"about 250 million tonnes of sawdust, close to 200 million tonnes of bar and over 400 million tonnes of other wood residues were produced"* (TDRI, 1983). The report also notes that about 60% of this material arose in developing countries and, whereas in the USA up to 80% of this waste was utilised, in developing countries large quantities remained unused. This comment might well be applied to other residues derived from agriculture as there are a number of factors which make the utilisation of residues easier in industrial countries. These include the presence of large combustors which can handle difficult fuels, and a greater access to investment capital and technical know-how. Additionally, fuel costs are higher in many industrial countries than in many developing countries so there may be greater immediate incentives towards conservation.

Although these numbers are interesting in setting a general perspective, they have to be immediately and heavily qualified for any practical assessment of the likely importance of any technology based upon residues. The issue is that agro-residues (hereafter wood-wastes are included in this general term) arise as a small part of a very complex economic and social process - the growing, marketing and consumption of crops. This process is, in most parts of the world, the key underpinning to almost all activities and it has a dynamic which is likely to be particular not just to a country but to the regions within a country or even to the immediate area of a community.

Agriculture is changing in most parts of the world and the disposition of residues is likely to be incidental to the main dynamics of such change. Any method of utilising residues has to follow the trends within agriculture; it cannot hope to influence them in any significant way. New crops or varieties of crops; new processing methods at new locations; new markets and routes to market; all these things are likely to alter more or less significantly the volume and location of residues. However, in making the decision to use any new procedure, the effect on residues will be considered, if at all, as a very secondary matter The reason for this is simple: the economic value of the crop is always much greater than any possible value placed upon the residue.

However attractive a residue-conversion technology may seem in terms of its efficiency or cost-effectiveness in producing fuel, it must conform to the existing local dynamics of agriculture or it will not be adopted.

Figure 1: Per Capita Cereal Residue Production (tonnes/year)

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It is likely that many of the trends at work in agriculture in developing countries, for better or worse in the overall sphere, will act to make the introduction of new techniques for residue use more attractive. Amongst these are the greater centralisation of processing to serve urban or export markets and the use of chemical fertilisers to raise yields and decrease dependence upon organic fertilisers, themselves very often based upon residues. However, this may be offset by other changes; for example the use of high-yielding varieties with a lower ratio of residue to crop or changes in landholding away from large farms to smaller units. In all situations, the introduction of any new technology has to fit in with these trends.

An example of such a change which has occurred in most Asian countries is the shift towards mechanised rice-milling. This occurs in a number of stages away from hand-milling in the household and towards centralised large mills. In the process of centralization, the residue ricehusk becomes a waste product which cannot be utilised in the immediate environs of the mill as, once, rice-husk could be used around a rural household. Thus in India, where central rice-milling is common, rice-husk exists as a waste product in large volumes whereas in Bangladesh, where smallscale milling remains normal, rice-husk is largely utilised by households. Such patterns of change are repeated, though in different ways, for most crops. The applicability of briquetting will depend very much on the particular form of agricultural practice in the region of interest. Huge volumes of residue can be swallowed up in some forms of agriculture and never be available for reprocessing.

It is sometimes assumed that residues are wastes and therefore "free" almost by definition. In practice, it is unwise to assume that any residue is "free" in the sense that it has no alternative use of some value. This is most obvious in the case of fully commercial briquetting plants based upon processing residues or wood-wastes. It is difficult to find examples of operating briquetting plants which do not have to pay something for the residues they use. Such payments may arise because there are competing uses for the "waste" but it may also arise simply because a residue provider is unwilling to allow someone else to make a profit from their wastes without asking for a share in the form of payment for the raw material.

Some plants operate using their own internally-generated wastes, particularly wood-wastes. These residues may seem "free" particularly if there are costs associated with waste disposal. However, in a country with a developed briquette industry, such as is beginning in Brazil, an alternative use may be the sale of the waste outside the plant to independent briquettors. Thus inevitably in a monetised economy, everything which has a use acquires a monetary value.

Even when this is not true, the wastes may, in practice, have various uses in the local community despite being given no monetary value. Such situations are likely to be well understood within the community even when they are not so apparent to the outside observer. Attempts to utilise the residue without offering any compensation are unlikely to be successful. Even when compensation is made, it may be that payment is made to someone other than the person to whom the original benefit so the result may be social disruption of some kind.

In general, it is probably unwise to assume that any "waster has no alternative use without careful investigation.

The broadest classification that can be made of residues is into field residues and processing residues, that is residues which remain in the fields after harvesting and those which arise during some further processing of the crop.

Field residues

In order to analyse the conditions under which briquetting of field residues may be applicable it is convenient to start with the volume of residues produced per unit area of cultivation. Barnard and Kristoferson show the data of Fig 2 which summarises the residue production of six common crops in terms of high, medium and low yields.

It can be seen from this that, whilst highyielding maize can give as much as 11 t/hectare annually, a more likely yield in most developing countries would be 25 t/ha with rice being the highest yielder. Other crops could be added to this list, some with rather higher rates of residue production. For example, cotton grown in Nicaragua is reported to produce 4-20 tonnes/ha annually with a mean of 8 tonnes (Svenningsson 1985), though this is high in comparison with figures quoted for the Sudan of 2.1-3.6 t/ha (Biomass Technology Croup 1987). However, the broad figure of 2-5 t/ha seems acceptable for a general analysis.

Only a fraction of this would be practically recoverable though under conditions of highly mechanised harvesting with associated straw baling, the fraction could be close to one. However, mechanised baling is likely to be uncommon in developing countries and a more realistic recoverable fraction might be closer to 50%. In any practical evaluation of a field-residue briquetting plant, the likely recovery rate would be a critical factor.

The recovery rate would be lowered by alternative uses for the residue particularly informal, though important, uses by local people. These could include animal feed and bedding, direct use as fuel and various building applications in thatch or mudbricks. In addition, the ploughing in or burning of residues may play a part in promoting soil fertility. Field residues seldom have significant commercial applications; that is why they are left behind. However, these informal uses may be of great significance locally.

Soil Fertility

It is unlikely that briquetting would deny local people access to residues. The very nature of field residues makes them difficult to secure against systematic informal gathering. A more likely consequence is that where a number of other uses existed for the residues, the practical recovery rates would be low compared with theoretical yields. The impact on soil fertility, particularly trace elements, if the residues are usually burned in the fields, might be more significant and, in this situation, deleterious effects might not be immediately noticed.

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The issue of soil fertility and the recycling of residues is not well understood. There seems to be little nutritional value in the direct restoration of uncomposted residues to the soil. However, they may play a part in maintaining the quality of the soil by keeping up its organic content. It is also possible that the burning of residues in the fields plays an important role in supplying trace elements. Certainly there is no generalisation which can be made; the importance of any one of these factors will depend critically upon specific local circumstances. The difficulty is that, in any specific situation, there is likely to be very little local knowledge about what impact a sudden change in residue recycling patterns would have on the soil. In principle, monitoring of agricultural yields after the change should indicate whether any adverse effects have resulted. In practice, such monitoring would be complex and expensive whilst changes could easily be hidden in the normal fluctuations of agriculture.

Land Needs

Briquetting machines have size ranges upwards from 0.1 t/h of input material. (Nominal size ratings are usually for woodwaste; a plant using straw would be substantially aerated over such figures.) If it is assumed that the smallest machine which would be commercially sustainable on its own would be 0.5 t/h then, at a recovered residue value of 1.5 t/ha, such a plant, working 6 months in the year, would require about 600 ha of land to supply its residue.

Figure 2: Residue Yields of Major Crops (tonnes/hectare)

The technical needs of a briquetting machine are best suited to a continuous homogeneous feed though not necessarily one based upon a single residue. The problem of maintaining a standard mix of different residues might be large however and a plant would probably be best served by a single type of residue input. This means that the plant assumed above would need over 600 ha growing a single crop, most of whose residues could be devoted to briquetting.

This area of land would comprise a very large farm unit in most parts of the world apart from those devoted to cattle rearing. This means that to be feasible, a field residue plant would usually have to draw upon several farms and be confident that their cropping patterns would not switch so as to leave the plant without adequate residue supply. This means, in turn, that local agriculture should be extensively based upon a single crop. Such conditions would be met in the rice-growing areas of Asia and maize areas of Africa but might be less easy to meet elsewhere.

Field residues are bulky; baled wheat straw has been put at 90 kg/m^3 (World Bank 1986) and stacked cotton residues at 55 kg/m^3. Even when chipped, cotton residues only have a bulk density of 130 kg/m^3 (Svenningsson 1985). By contrast, stacked wood has a bulk density above 500 kg/m^3. This means that the transport of residues to a briquetting plant can become increasingly expensive as the distance from the site of the residues to the plant increases.

A survey of straw-briquetting plants in Germany (KTBL 1983) contains costs which suggest that as the distance from field to plant increases from 1 km to 10 km, the cost of the briquettes increases by between 16-22 DM/t (10-14 US$/t). Field collection and baling costs are also high: 29 DM/t for collection in a 0.5 ha field though this could drop to 11 DM/t in a big 10 ha field making use of large baling machinery.

These German costs are likely to be rather higher than would be incurred in a developing country because of comparative labour costs. However, it is unrealistic to expect residues to be transported without mechanisation in any country and the capital costs alone of the necessary equipment can be high.

In a feasibility study for a wheat-straw plant in Ethiopia (World Bank 1986), it has been estimated that, even working under near-ideal circumstances of a large statefarm producing the 5 000 tonnes/year of residue required by the project, 6 tractors, 5 trailers and 3 balers would be required to cope with residue collection and transport. The capital cost of this equipment is put at US$107 000 . This may be an overmechanised plant for other circumstances but clearly the costs are high for any plant based upon a residue supply which is at all remote from the briquetter.

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These simple sums suggest the residue context in which briquetting could be applied; a fairly large area of monoculture in which a uniform residue arises in the fields within a distance of ready transport to a central processing point. What exactly constitutes "ready transport" will, of course, vary widely but even under the most ideal circumstances it would be necessary to transport the residues a few kilometres. (A circle with area 2 000 ha has a radius of 2.52 km and this is the ideal geometric configuration.) This means that mechanical transportation is certainly required with the consequent capital costs.

A context such as this possesses many associated advantages; notably that such a large area of monoculture is likely to use chemical fertilizers, which means that soil fertility issues may be minimal, and is less likely to have a significant part of its residues used for other, informal needs. However, it is also clear that such situations are fairly rare and remote from the conditions of mixed, subsistence agriculture which characterises the rural conditions of many countries.

There are numerous examples of this type of briquetting operation based upon maize cultivation in the USA and, rather less common, on wheat straw in Europe. Until recently examples in developing countries have been rare. However, some recent projects suggest that such plants may be developed more often in the future.

In Ethiopia, there are plans to build pilot plants based upon wheat, maize and cotton residues under just such circumstances of large state farms devoted mainly to a single crop (World Bank 1986). In the Sudan, a semi-mobile briquetting plant has been installed to utilise cotton-wastes from the huge cotton-growing areas of the Gezira (the plant is mobile as wastes cannot be removed from the fields to avoid infestation), whilst in Nicaragua, a fixed plant is fed by chipped wastes from the cotton fields (Svenningsson 1985). All these are based upon conventional piston-briquetters. A more unusual plant based upon cotton-residues, using a lower cost technology and producing charcoal briquettes for the domestic market is also under investigation in the Sudan (Biomass Technology Group 1987).

It is difficult to make any clear rules about the minimum land area required, in practice, to operate a briquetting plant. In Germany, a plant has been reported operating on as little as 45 ha though using a small machine and with high residue yields. A much more common size would be 500 ha and in developing countries with lower yields, a level of 1000 ha would seem more appropriate.

The most likely sites for briquetting plants based upon field residues would be on land growing maize or cotton in single land parcels of at least 1000 ha and, for preference, rather more. Other cereals, such as wheat, might also be attractive but would require rather larger areas. It is possible that plants based upon rice-straw could be developed but the logistics of transportation in paddy-fields plus the common occurrence of multiple cropping would probably make the plant impossible to run. There are no known examples of plants based upon rice-straw.

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This land requirement is onerous though it is not necessary that the land should be under single ownership or control. In Europe, one form in which briquetting of cereal residue has developed is the purchase of a single machine by a cooperative of farmers. However, this is in a context where cooperative ownership and operation of machinery is quite well established.

No mention has been made of the equivalent to field residues in forestry, that is the branches, tops and even leaves, left behind in forest logging operations. The reason for this omission is essentially pragmatic: no briquetting operation based upon such residues has been located and it may be therefore assumed that its economic viability is very limited.

This is not to suggest that forest-residue recovery is not undertaken; in Sweden, for example, there is a considerable business in such recovery in the form of wood chips. However, the logistics of the operation with a very high degree of mechanisation in areas remote from the consumer seems to point towards the bulk use of wood-chips in large, centralised combustion-plants. The inherent moisture of forestry residues, at around 40%, is too high for immediate briquetting and forest drying is impractical. The bulk density of wood-chips, about 300 kg/m^3, is quite high so there is little potential saving in transport costs available after briquetting.

Although these conditions might not be precisely reproduced in developing countries, there does not seem any evidence yet that briquetting has any role to play in the utilisation of forestry residues. This is not true of sawmill and other wood-wastes from processing; these are considered below.

Process residues

In this category, we include all residues obtained from the processing of a crop or wood including, for example, bagasse from sugar-cane, coffee husks, groundnut shells, rice husks, coir dust, sawdust, furniture wastes, in fact a very long list indeed as nearly all crops produce some kind of residue. Virtually all of these residues appear to have been briquetted, particularly if one believes the lengthy citations contained in manufacturers' brochures. In principle, these claims may well be true as the briquetting process works quite well for a wide range of feedstocks provided they are homogeneous and contain below 15% moisture. "If you can shovel it then

If you can shovel it then you can briquette it" would be a reasonably sound motto for a briquettor. "If you can shovel it then you can briquette it" would seem to be a reasonably sound motto for a briquettor.

This means that evaluation of a plant based upon process residues is, in principle, less complex than for one based on field wastes. The main problem is to establish the quantitative availability of material from a limited number of point sources, possibly only one. This is inherently simpler than to establish the potential residue yields from shifting agricultural patterns of several outside farms. Factories do not easily shift the nature of their operations.

The scale of operation of briquetting machines is quite well suited to most processing plants in developing countries. Rice-milling in Thailand, for example, is undertaken in mechanised plants which commonly process between 25 and 500 tonnes/day. The proportion of husk in this is about 25% so between 8 and

125 tonnes/day of residue will be produced. These quantities could be absorbed by single briquetting units using either one or two larger piston machines or four or five screw presses. The former set-up is used in India, the latter has been adopted in Thailand.

Similar calculations suggest that a single briquetting unit could be adequately fed by the sawdust from a few sawmills with a combined throughput of about 100 tonnes daily. This grouping of small processing units of the same kind in a single area is quite common for most of the main crops and suggests that the feed basis for briquetting may exist in a number of countries.

The relationship between one briquetting plant and one or more small agro-processing units may well be the most favourable for the establishment of briquetting. Although larger processing units may offer a super-abundance of supply for a single machine and offer visions of large multimachine briquetting operations, such schemes do not seem, in practice, to develop. (Large multi-unit plants are planned in Brazil and Argentina but based upon a number of saw-mills rather than a single processor). The reasons for this are not clear; it is always difficult to explain a negative. However, the most likely explanation is that large plants are set up with built-in methods of waste disposal, usually in their own boilers possibly using specially designed combustion equipment.

This issue of alternative uses is the one which lies at the heart of all application of briquetting to process residues. Once the residue has been centralised then a range of applications may emerge...

This situation is most obvious with respect to sugar cane processing which is probably the biggest bulk agro-processing operation commonly found in developing countries. World production of sugarcane amounts to several hundred million tonnes mostly in developing countries. As about 25-30% of cane is residue, bagasse, this amounts to a very large volume indeed of residues, larger even than rice-husk of which there was about 50 million tonnes produced in 1984. However, very little bagasse ever emerges as a waste for it is consumed internally to generate steam and power in the sugar-mill. It has been suggested that much more efficient use could be made of this bagasse by optimising its combustion and selling power externally. However, even in the most prolific producer, Brazil, no briquetting based upon bagasse has yet emerged even though surplus bagasse amounting to tens of millions of tonnes emerges and there is an established briquetting industry, based upon other residues.

Part of the reason for this lack of interest lies in the high moisture content of bagasse, about 50%, which necessitates a separate drying stage. However, this problem has been accepted in the briquetting of sawdust and presents no technical difficulty. The major reason appears to be that the scale of bagasse production encourages the installation of special combustion systems at a few larger plants able to cope with the residue directly without any intermediate treatment. In this situation, the extra costs of briquetting can only be justified on a transport-saving basis which may not be a strong enough incentive.

This issue of alternative uses is the one which lies at the heart of all applications of briquetting to process residues. Once the residue has been centralised then a range of applications may emerge both as a fuel and in other sectors which were not apparent when the crop was processed locally either manually or in small units. In effect, the transport costs of gathering, which are the main barrier to utilization of crop residues, have been absorbed by the transport of the valuable food-component of the crop.

Direct combustion is usually the one option of most relevance in the energy field whilst other uses may include animal feed-stuffs and bedding or such, at first sight unlikely, uses as additions to cement making (rice-husk) or packing for car-doors (bagasse). In all these applications, the users will compete for the residue and the briquettor may have to pay high prices for a residue once considered "free".

At the other extreme, a briquettor tied to a particular process residue from a single plant may find itself stranded if the supply of residues fails to meet expectations as the plant itself fails to find any raw material. There are a number of plants, particularly in Africa, where changes in agricultural practice or simple miscalculation have meant that the feed-plants have simply not delivered enough residues. The small value of the briquettes relative to the total value of the crop meant that the issue of providing briquetting raw-material was irrelevant to the wider agricultural changes going on.

Some reasonably successful briquetting operations have been set up attached to a single processing unit with no alternative source of supply, but they are rare. The most prolific conditions for operation, and this applies to plants based upon field residues as well, are units based upon small-scale processing of a crop or wood which is quite widely based. The obvious examples are rice-husk and wood-processing if the latter is taken to mean small sawmills and furniture plants.

Chapter 3.The markets for briquettes

Energy markets like agriculture are complex and changing entities with many national and local peculiarities. If one has to attempt to characterise the role of briquettes in these markets it would be in terms of the answers to two key questions:

- can the particular briquette be burnt satisfactorily in the combustion appliance used by a particular consumer?
- does the price at which they are sold compete with the fuels normally used?

The form of the first question is important for it suggests an implicit answer to another question: Will consumers alter their normal combustion appliances to suit briquettes? The answer to this is almost invariably: No. The reasons for this definite answer are twofold. First, in terms of quality of combustion, briquettes do not offer any significant advantages that might persuade consumers to spend money on new appliances. They are neither very convenient nor smoke-free; in contrast to electricity or LPG, both fuels for which consumers have shown themselves ready to switch appliances. They are essentially a small variation on a basic and not particularly attractive theme of solid fuels.

Some industrial consumers may be prepared to make adjustments to their boilers and domestic consumers may shift their fuel-feeding patterns if, in both cases, they can see a financial advantage. But it is difficult to envisage - and impossible to find in practice - any situation where consumers are prepared to shift to new appliances.

There is a crucial difference to testing new appliances for a fuel which has wide existing circulation and attempting to introduce new appliances for a novel: and minor fuel.

Second, the likely size of briquette supply relative to the total fuel supply even to a particular market sector is going to be small. Even the most optimistic view could hardly suppose that briquettes will ever supply more than 5-10% of, say, the total household market in any particular region of industrial demand. At these kind of penetrations with no prospect of the proportion increasing, consumers will always be aware of the need to give themselves an alternative source of fuel. This will certainly be true in the early stages of marketing briquettes whether or not, at a later stage, some consumers would have the confidence to commit themselves wholly to briquettes. Thus briquettes have to be compatible with existing appliances if they are to have any chance of achieving initial market penetration.

Of course, it is always possible to persuade some consumers to use new appliances if they are given them as part of a testing programme and then supplied with free or subsidised fuel. Such testing is a necessary part of any appliance programme, for example, to introduce more efficient wood-stoves. However, there is a crucial difference to testing new appliances for a fuel which has wide existing circulation and attempting to introduce new appliances for a novel and minor fuel.

Briquettes must therefore be compatible with existing appliances with little or no modification if they are to have any chance of successful marketing. The range of appliances can be divided, broadly, into three:

- open or semi-open cooking stoves which use wood or charcoal in households or small commercial operations;
- enclosed stoves or furnaces, based upon wood or coal, used in industry or commerce for heating water or raising steam;
- kilns of various kinds for brick or ceramic making normally burning wood.

Appliances based on oil or gas-burning are almost invariably unsuited for briquettes.

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The household market

In the household sector there is relatively little data about the acceptability of briquettes as a wood substitute. Ordinary briquettes cannot substitute for charcoal; for this various kinds of carbonised briquette have been developed which have met with variable success. Rather few projects have ever attempted to sell ordinary briquettes direct to households and virtually all of these have met with commercial failure usually connected with problems of residue supply, machine failure or price uncompetitiveness.

The only systematic market study, which we have located (Association Bois de Feu 1985), which looked at domestic consumer response to briquettes gave quite optimistic results. Briquettes were burnt on ordinary stoves mixed with fuelwood and the specially modified stoves which were distributed were not required. Indeed it was claimed that briquettes could even acquire a cachet of modernity (though it was not reported whether this would imply acceptance of a price differential making briquettes more expensive).

This result is encouraging and does refute totally negative views about the potential use of briquettes in the household sector. But a single, limited survey cannot be used to prove universal acceptability. The Niger project failed because the supply of residues proved inadequate and briquettes could not compete in price with firewood so no extended market tests were made.

The only situation where uncarbonised briquettes appear to be sold commercially to households is in Thailand where sawdust and, to a limited extent, rice-husk briquettes are sold to refugee camps. However, this is a rather negative recommendation as sales to other types of households have proved unsuccessful and the refugee camps are forbidden to use fuelwood. The reason for the failure in other sectors is largely price-based; fuelwood remains rather cheap in Thailand. Rice-husk briquettes are also disliked because of their high ash content (over 20%), something which would probably prove an insuperable barrier for this material in normal household use.

Nevertheless, technically there does not seem to be any major problem about using briquettes in the existing appliances. Certainly no new or modified appliances have been developed though it is possible that the performance of briquettes is inferior to wood were it to be available.

There have been efforts to sell carbonised briquettes to households, mainly in India but also in Thailand and some places in Africa. The Indian efforts have not been very successful, though again this was using rice-husk as the base material. Carbonised wood-briquettes are largely indistinguishable from ordinary charcoal and are quite acceptable. Test marketing of carbonised briquettes in the Sudan is claimed to have been successful.

Laboratory tests are not a good substitute for genuine consumer use as they cannot reproduce all the complexities of practical application. But, such as they are, most tests suggest that, although the combustion characteristics of briquettes are somewhat different to wood, they are not so different as to require device modification.

The issue of household acceptability of briquettes made from materials other than rice-husk must remain open as no full commercial marketing has yet been undertaken. The preliminary results of test marketing offer reasonable grounds for optimism however.

It is probable that at least the smaller diameter briquettes, in particular the hollow examples from screw-presses, would find acceptance, possibly used with wood for initial ignition and heat-raising. It would probably be more difficult to sell

The issue of household acceptability of briquettes made from materials other than rice-husk must remain open as no full commercial marketing has yet been undertaken the bigger sizes, say about 8 cm diameter, simply because the physical dimensions of household stoves are limited. Large logs would be similarly rejected. Piston briquettes can be readily split into disks but this causes losses and may not be liked by consumers.

Industrial and commercial furnaces and kilns

In the other markets, for example, industries based on wood or coal, brick-kilns, bakeries, commercial establishments such as hotels, restaurants and other places with heavy hot-water demand, the issue is rather simpler than in households. There are many examples of briquettes being burnt in various enclosed stoves and kilns with very few problems.

The only practical difficulty found is the very high ash content of rice-husk briquettes. Whilst there does not seem any other comparable material, ash-contents of 510% are quite common and ash problems might arise with other materials.

Rice-husk briquettes have been sold fairly readily in India in industrial establishments with coal-burning boilers. However Indian coal is high-ash and so industries are prepared to cope with the problem. However, even in coal-burning boilers, most sales go to particular designs of boiler, notably step furnaces, in which the rice-ash moves out of the combustion zone. Rice-ash is almost entirely silica and it can fuse together into a clogging mass if the temperature is too high. This has been a problem in marketing rice-husk briquettes in Brazil to customers used to burning wood in their boilers.

Problems of ash-fusion could occur using lower-ash materials, though this has not been reported. In general, small wood-burning boilers may run at lower temperatures than coal units and, in wood units, most types of briquettes burn very well.

In Brazil, industrial consumers are actually prepared to pay a premium over the wood price for briquettes (these are mainly wood-based) of up to 50%. This is because briquettes are of uniform size and quality, are dry, and are purchased by weight. This last is important in Brazil, and possibly elsewhere, as wood is purchased by volume from a lorry and there are constant reports of suppliers cheating by packing the interior of the load with inferior material stacked randomly.

A recent study of a Ghanaian plant has also reported (World Bank 1987) a readiness by bakeries to pay a premium price for briquettes.

In most places, the market for briquettes in industry is large enough to absorb all the present and the likely future output of briquettes. Because of this and the ready acceptability of briquettes in industrial use, it is an obvious marketing strategy to focus on this market to the exclusion of household consumers.

In Tanzania, a project set up to produce carbonised briquettes for households has taken this line of marketing and is, in practice, selling all its output, uncarbonised, to small industry and commercial users.

There may be reasons of social policy to focus on household use, something which is reflected in various projects to produce carbonised briquettes as a charcoal substitute. There are also continuing efforts to produce low-cost briquetting machines which can operate on a small scale at the village level to produce a household wood substitute. Even in this area, it is worth noting that the only semimanual briquetting plant, known to operate on a commercial basis, sells its output to local brick-kilos. This plant operates in the east of the Sudan using semi-rotted bagasse as its raw material.

It must be acknowledged that, in virtually all situations, the industrial market has proved the easiest for briquettes to penetrate.

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Can briquettes compete?

The second question concerning the price competitiveness of briquettes can only be adequately answered by reference to specific local conditions. In general, however, the level of current wood-fuel prices in large parts of Africa, Asia and Latin America are too low to allow briquettes much competitive room. In order to compete, briquettes often have to be sold without any capital charge component and, even then, may not cover their operational costs.

The failures of briquettes to compete with fuelwood prices is repeated from Niger to Thailand and at many places en route; it is without doubt an international conclusion. To appreciate the circumstances in which briquetting may be economic, it is useful to review, briefly, the two countries, Brazil and India, where an infant briquetting business has been established.

In India, the main residue used is rice-husk which, despite its drawback of high ash content, is very widely available and can be readily briquetted without any drying or chipping. This last point means that capital costs of the total plant can be kept down, something which is aided by local manufacture of machines.

The existing fuel at which briquettes are aimed is coal, which is often of poor quality and whose supply, particularly to smaller industries, may be irregular. It is also expensive; the price varies by region: in Delhi it may cost over 80 US$/t while fuelwood was reported to be 50-70 US$/t.

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The rice-residues are not free as, over the past few years, a number of industries in rice-producing areas have converted to direct firing of husk. This means that the rice-mills have become able to charge up to 250 Rupees/tonne (20 US$/t) though a more usual price is 100150 R/t. The direct use of rice-husk close to the mills mean that the best markets for the briquettes are often rather far from the point of production. In effect, briquettors are taking advantage of the fact that the unit transport costs of briquettes are lower than those for loose rice husk.

Briquettors in India estimated that they could break even at a factory-gate price of 550-600 R/t which implies a price of about 3040 US$/t net of the cost of rice-husk. Such prices were achievable but did not allow for any large profit.

In Brazil, although some use has been made of rice-husk, most of the briquetting plants utilise wood-wastes which require preliminary chipping and, sometimes, drying. The use of wood-waste means that the throughput of machines is quite high whilst the local plant manufacturer offers very cheap machines. These two factors lower capital costs considerably.

The residues are cheaply available, perhaps 35 US$/t, where they are not actually free as there are almost no alternative uses. Most wood-waste is dumped.

The target fuel with which briquettes compete is wood used in industry, an area of fuel use which has grown considerably in the last few years as the Brazilian government has supported a major biofuel programme. The wood supply is not of consistent quality however, in particular it may contain up to 50% moisture. There is also a good deal of cheating by wood fuel suppliers.

Wood prices are regionally variable but are still not high even in the higher price areas. In Sao Paula, wood prices of 13-16 US$/t were quoted. Briquettes are sold at 25-40 US$/t; prices which at the upper end seem to offer a reasonable profit. Briquettes can be sold at a premium over wood because of their lower moisture and consistent quality.

Three conclusions emerge from the case-studies in Brazil and India despite the big national differences.

First, it is necessary to keep capital costs down to a minimum by purchasing cheap, though obviously reliable, machines and not over-engineering the rest of the plant. Capital costs are also minimised by working the machine for at least eight months in a year even with a seasonal crop like rice. Large stocks of husk may have to be kept.

Second, it helps to have a fuel against which to compete which may be of unreliable quality and suffers from irregular delivery. ibis may enable a premium to be charged for briquettes.

Third, in order to break even, a factory gate price of 30-40 US$/t not including residue costs, is required to make a small profit even if capital costs have been minimised. Additional capital cost items, such as a dryer, and any costs associated with collection, storage and handling of residues can raise this by 50-100%.

It is this conclusion which shows why, to take a single example in Nairobi, a plant which possesses a briquetting machine has reverted to burning wood as its main fuel burning wood as its main fuel It helps to have a fuel to compete

It helps to have a fuel to compete which is of unreliable quality and suffers from irregular delivery.This may enable a premium to be charged for briquettes after considerable trials with coffee-husk briquettes. Industrial fuelwood costs under 20 US$/t, at which price it is difficult to cover the operating costs of briquettes. It is not possible to charge a premium for briquettes as wood is usually of reasonable quality. Clearly the incentives for setting up a new plant are small in such circumstances.

Chapter 4.Technical aspects of briquetting

History of briquetting

The compaction of loose combustible material for fuel making purposes was a technique used by most civilisations in the past, though the methods used were no more than simple bundling, baling or drying.

Industrial methods of briquetting date back to the second part of the 19th century. In 1865, a report was made on a machine used for making fuel briquettes from peat which is a recognisable predecessor of current machines. (A drawing of this machine is reproduced in Fig. 3 by courtesy of the British Institution of Mechanical Engineers.)Since then there has been widespread use of briquettes made from brown coal, peat and coal fines. There are various processes which produce artificial smokeless fuel briquettes from coal fines.

The most common technique used in this type of process is some form of roller press using only moderate pressure and a binder. This type of plant is also used to make all kinds of non-fuel briquettes from inorganic material such as metal ores. Various binders are used; one of the most common is lignin derived from paper-pulp manufacture.

Figure 3: Drawing of 1865 Peat Piston Briquetter

The briquetting of organic materials requires significantly higher pressures as additional force is needed to overcome the natural springiness of these materials. Essentially, this involves the destruction of the cell walls through some combination of pressure and heat. The need for higher pressures means that the briquetting of organic materials is inherently more costly than for inorganic fuels.

The use of various forms of organic briquetting seems to have been common both during World War I and during the '30s depression. The modern mechanical piston briquetting machine was developed in Switzerland based upon German developments in the '30s. Briquetting of sawdust and other waste material became widespread in many countries in Europe and America during World War 11 under the impact of fuel shortages. Parallel needs pushed the Japanese into refining the screw machine discussed below. After the War briquettes were largely squeezed out of the market by cheap hydrocarbon fuels.

The use of organic fuel-briquettes, mainly in industry, was revitalised during the period of high energy prices in the '70s and early '80s, especially in Scandinavia, the USA and Canada.

In Japan, briquetting seems to have been common until recently with widespread use of "Ogalite" fuel briquettes made from sawdust. The Japanese technology has spread to Taiwan and from there to other countries such as Thailand. Japanese, and later Taiwanese, briquetting has been based almost entirely upon the use of screw presses which, although originating in the USA, have been more widely adopted by Asian than European or American manufacturers. Such briquettes were widely used in Japan during the 50s as a substitute for charcoal which was then still a widespread fuel.

Piston presses

It seems quite clear that the development of the modern type of mechanical piston press started in Switzerland during World War II though based upon work done in Germany in the '30s. The Swiss developments were centred around Fred Hausmann and the Glomera press though he was not its original inventor.

Patents and licensing rights changed hands during a period when partnerships were broken up and companies went bankrupt or were bought by others. Whatever the precise situation about original invention, Hausmann undoubtedly played an important role in making the piston-press technology well-known all over the world. In many places the name Hausmann is often equal to a mechanical piston press. Thus the Brazilian industry, certainly the largest outside North America, was begun by a company in which Hausmann was a founding partner, whilst in India one of the main manufacturers began with a licence from Hausmann.

No patents governing the general design of this type of press are effective today and most of the manufacturers of mechanical piston presses identified in this study owe their designs to the original Swiss patent. The nearest current descendant of the first piston press manufacture is, by their own claim, Pawaert-SPM.

The piston press acts in a discontinuous fashion with material being fed into a cylinder which is then compressed by a piston into a slightly-tapering die. The compressed material is heated by frictional forces as it is pushed through the die. The lignins contained in all woody-cellulose materials begin to flow and act as a natural glue to bind the compressed material. When the cylinder of material exits from the die, the lignins solidify and hold it together to form cylindrical briquettes which readily break into pieces 10-30 cm long.

The diameter of the briquette is closely related to the output of the machine. A unit producing 1 t/h of briquettes will have a die 8-10 cm in diameter. This relationship is rather inflexible and may constrain potential markets for the product of bigger machines. Small stoves may not be able to burn such large pieces.

Piston-presses can be driven either by mechanical means from a massive flywheel via a crankshaft or hydraulically. The mechanical machines are usually larger, ranging in size from 0.45 to 0.3 t/h, whilst hydraulic machines normally range up to 0.25 t/h though some models are somewhat larger.

Mechanical presses generally produce hard and dense briquettes from most materials whilst hydraulic presses, which work at lower pressures, give briquettes which are less dense and are sometimes soft and friable.

Piston presses are reliable, once they have been installed properly with dies shaped correctly for the raw materials used. Problems arise if the die has not been shaped correctly or if the feeding mechanism has not been sized for the material to be used. It is normal for machines made in Europe to be designed to operate on wood wastes; the use of agroresidues normally de-rates the throughput and may require some modification to the feeder. Such an output aerating may result in a significant increase in capital charges.

Figure 4: Typical Piston Briquetting Press

It is normal for machines made in Europe to be designed to operate on wood wasted ;the use of agro-residues normally de-rate the throughput and may require some modification to the feeder. Such an output derating may result in a significant increase in capital charges.

Maintenance costs are fairly low amounting mostly to replacing the die every few hundred hours, the precise time depending upon the material. Some feedstuffs, such as rice-husk, may be particularly abrasive on dies. It is important, however, that regular maintenance is undertaken. The heavy, discontinuous action of the piston means that small imbalances and irregularities can quickly become major defects.

Piston presses with hydraulic drives, as distinct from those using mechanical drives with flywheels, are manufactured in the relatively limited geographical region of Western Europe. It is a fairly recent development of the mechanical press for use with light materials where the quality of the product is of less concem. The forces in a hydraulic machine are less violent than in a mechanical unit and they may therefore need less attention.

Typical materials suitable for hydraulic presses are paper, cardboard, manure, etc. though the hydraulic press can in some cases become an alternative to a mechanical press. Since it is normally made with lower capacity than the mechanical press, it is suitable for taking care of waste material from small wood processing industries. Briquettes from hydraulic machines are often used onsite as they may be too soft for much transportation

Screw presses

The earliest development work on screw presses was carried out in the USA in the 30's resulting in the widespread use of the PRES-TO-LOG model which was based on the conical type of extruder currently found in the Belgian Biomat design. During World War 11, a Japanese design which featured a heated die and a prolonged tapered central shaft of the screw resulting in a hollow briquette, was being developed. It was very successful and one of the manufacturers in our study claims to have sold 600 units. The design has been taken up by other manufacturers in Asia and more recently in Europe.

In the screw-presses, material is fed continuously into a screw which forces the material into a cylindrical die; this die is often heated to raise the temperature to the point where lignin flow occurred. Pressure builds up smoothly along the screw rather than discontinuously under the impact of a piston.

Figure 5: The PRES-TO-LOG Briquetter

If the die is not heated then temperatures may not rise sufficiently to cause lignin flow and a binding material may have to be added. This can be molasses, starch or some other cheap organic material. It is also possible to briquette carbonised material in a screw-press and in this, as lignins have been destroyed, a binder has to be employed. Some low-pressure piston machines may also require the use of binders though this is unusual.

If the die is heated then the temperature is normally raised to 250-300 °C, which produces a good quality briquette from virtually all organic feeds provided the initial moisture is below about 15%. The briquettes from screw machines are often of higher quality than from piston units being harder and less likely to break along natural fracture lines.

Screw presses are usually sized in the range 75-250 kg/in though larger machines are available.

The capital costs of screw machines may be a little less than piston units though because of size differences it is difficult to make direct comparisons. However, their maintenance costs are usually much higher because of the considerable wear on the screws which have to be re-built rather frequently. They also have a higher specific energy demand than piston machines.

However, maintenance costs of screw presses are usually much higher because of the considerable wear on the screws which have to be re-built rather frequently.

Figure 6: Typical Screw Briquetting Machine

Pellet presses

These operate by extruding small-diameter (10 to 30 mm) pellets through a die which has many holes. The extruding mechanism is often an eccentric roller which moves inside the large cylindrical or conical die.

Such machines were originally developed for the production of animal feedstuffs and mineral-ore pellets. They are expensive and have high through-puts of 5-20 t/h for a single unit.

The smaller product size and high capacity of these types of presses was before the 60's utilised only in the pressing of fodder pellets and similar applications. Since then a limited number of energy applications have materialized in the USA (Woodex), Canada (Bioshell) and in Europe (Sweden, France and West Germany). There have been a few applications of pellet presses in developing countries solely for energy purposes, notably Kenya, Zimbabwe and Zambia. The latter two examples are both defunct however and it is doubtful if the high capital cost and power consumption of this process makes it a viable proposition.

Manual presses

This report concentrates on equipment suitable for industrialized production of briquettes, albeit on a small scale. We are largely omitting the numerous types of hand-driven or animaldriven fuel-forming equipment found in literature and, possibly, used in some parts of the world. Several researchers have proposed schemes for developing equipment suitable for briquetting of agricultural waste on the village level (Scarab 1983). The "green fuel" scheme in Indonesia and work in Thailand by Prof Watna Stienswat is aimed at solving the problem of finding suitable technology for small-scale (<100 kg/in) operations. They operate with wet, i.e., green, material forming, rather than densifying, the material into a briquette that is then solar dried. There has also been work on manually produced briquettes undertaken in Indonesia. (Johannes, 1982)

Another interesting development has been seen in Sri Lanka in which large briquettes are formed from coir dust in a baling press between plates of corrugated steel. Lime is mixed in with the coir dust to make the briquette suitable for handling after solar drying. The method has prospects to offer a relatively inexpensive way of producing briquettes in small as well as larger plants.

It remains unclear, however, whether any manual or semi-manual densification process can ever be commercially viable even in circumstances where labour is very cheap. When allowance is made for their very low throughput, such techniques often require almost as much capital investment as the mechanical processes. The savings achieved are essentially a labour for electricity substitution rather than labour for capital.

Two semi-manual plants making briquettes from semi-rotted bagasse are known to be operational in the Sudan (Paddon, 1987) and are quite successful commercially. Their circumstances are unusual however they are based on Ethiopian refugee labour - and it might be difficult to replicate them elsewhere. However, manual processes do have the great advantage of being able to handle wet wastes which cannot be utilized mechanical processes.

Manual presses cannot be made to generate sufficient pressure to break down cell walls and they cannot, therefore, produce densified briquettes. This means that they cannot realise any significant degree of transport cost savings.

As the application of manual presses is likely to be limited to special cases, one problem with their development is that it is difficult to justify producing specific machines for the job as the initial costs are too high. In the Sudan, manual brick-making presses have been adapted for the purpose. One drawback of this is that the initial chopping, mixing and feeding operations are very dirty and arduous; the actual briquette making part of the process is the easiest.

It remains unclear however whether any manual or semi-manual idensification process can ever be commercially viable even in circumstances where labour is very cheap.

Briquette. Characteristics

Briquetting and pelletization are justified mainly by the reduction in volume of a bulky waste material. After densification, there are two main quality aspects of the product:

- (i) that it shall remain solid until it has served its function, and
- (ii) that it shall perform well as a fuel.

The first aspect, that the product should not crumble and disintegrate when handled, stored and transported, is mainly a function of the quality of the densification process for a given raw material. The second aspect is mainly related to the properties of the raw material and the shape and density of the individual briquette. In the following we will call these factors

- (i) briquette handling characteristics and
- (ii) fuel characteristics.

The distinction is not always clear and sometimes they interfere with each other. For example, improving the handling characteristics by making a more dense briquette often has a detrimental effect on its combustion behaviour

In principle, in planning a project it is possible to begin with the various demands of transportation, handling, storage and combustion and then to choose a machine which, for a given raw material, produces a briquette which possesses just the required characteristics. In practice, this is seldom possible given that commercial machines tend to have concentrated on a rather limited range of product options. This is particularly important in developing countries as most processes have been developed with other markets than agro-residue briquetting in developing countries in mind. One such example is the hydraulic piston press. It has been developed to work in small wood working industries with waste flows smaller than about 0.1 t/h and where the briquettes are intended for combustion in in-house boilers. Thus it does not matter that the briquettes produced are rather soft. However, such briquettes are likely to be unsuitable in any circumstances where the briquettes are transported

Mechanical piston briquetters, on the other hand, make harder briquettes but they are more sensitive to foreign particles in the material flow. A nail for example is likely to destroy the die and piston top of a mechanical piston machine while it would probably pass through a hydraulic machine unnoticed.

They also produce large briquettes which may not be suitable for the proposed combustion device.

Thus, in practice, some compromise between desired characteristics and what machines are commercially available may be necessary.

Before discussing in more detail the various characteristics of briquettes, it should be pointed out that the briquette handling characteristics are not likely to cause severe problems in a project, other than in cases where there has been a plain mismatch between material, process and purpose. Combustion properties are more critical, especially when trying to introduce briquettes in the household sector, but also when they are intended for combustion in industrial boilers.

Handling characteristics

Density

Most processes are capable of producing briquettes with densities above 1 000 kg/m³, i.e. the individual briquettes will sink in water. (This is, in fact, a good if crude test for the briquette quality.) The upper limit for the density is set by the physical density of each raw material which, for ligneous material, is about 1 500 kg/m³. The density of individual pieces is termed apparent density. High pressure processes such as mechanical piston presses, pellet presses and some screw extruders, make briquettes in the 1 200 1 400 kg/m³ density range. Hydraulic piston presses make less dense briquettes, sometimes below 1 000 kg/m³.

Briquette handling characteristics are not likely to causes severe problems in a project, other that in cases where has been a plain mismatch between material, process and purpose. Combustion properties are more critical.

There is little point in trying to make even denser briquettes because combustion properties are likely to suffer. The benefits are small because the more important property of briquettes is their bulk density, that is the overall density of many pieces piled together.

The bulk density is a function of both the density of the individual briquette and its geometry. There are differences in bulk densities between large and small briquettes and pellets, but for broad calculations a factor of two between apparent and bulk density can be used (CRA 1987). This means that for briquettes with apparent densities in the 1 200 - 1 400 kg/m³ range, the resulting bulk densities are 600 - 700 kg/m³. For comparisons, the bulk density of the raw material could be as low as 40 kg/m³ for some grades of bagasse to about 150 - 200 kg/m³ for a variety of agro-residues and wood wastes. The higher bulk density of briquettes will significantly increase the distance over which it is economic to transport a residue in order to god a market for it.

In briquetting, the resulting density is affected to a significant degree by the particle size of the raw material. Finely ground material, for example sanding dust from wood plants, will make very dense briquettes but requires high pressures and temperatures to agglomerate without a binder.

The density of the product is also affected by the moisture content. Water in the raw material will prevent the compression of the briquettes and the steam that evaporates from the material due to the high temperatures will leave voids which decreases the apparent density. If the briquettes later pick up humidity from the air, the result is a swelling of the material which also decreases the density. This process can lead to the total disintegration of the briquettes.

Friability

This factor is a measurement of the briquette's resistance to mechanical action that will affect them when handled and transported. Tests can be done either in a rotating drum or by repeatedly dropping samples from a specified height. In both methods, the samples are screened (20 mm sieve) and the fraction retained is used as an index of a briquette's friability (CRA 1987).

It is difficult to give a figure for an acceptable friability index as the relationship between test results and reality has never been studied. In the work carried out by CRA some samples received an index of 0, i.e. the briquettes had disintegrated entirely after a certain time, which clearly indicates an inadequate briquette quality.

When the briquettes score higher in tests, say between 0.5 and 1.0, such results are more difficult to interpret. They do have a function though when comparing several processes in order to find the most suitable for a given material.

General observation at a number of operating plants suggests that briquettes produced by mechanical piston-presses and screw-presses are hard enough to be transported by lorry for considerable distances without degradation. No plants using such machines complained about losses due to product disintegration. One or two plants using hydraulic presses did find that the product was too soft for transportation.

Resistance to humidity

Inherent binders (lignin) and most externally added binders are water soluble. This results in one of the weakest points in briquette quality, which is that briquettes must not be subjected to water or humid air. Briquettes and pellets have to be stored under cover and they do have a limited lifetime under humid conditions. The latter problem appears to be only minor even in tropical countries. The dense, hard-surfaced briquettes produced in mechanical piston presses and screwpresses with heated dies have enough resistance to humidity to withstand the rainy season in India, Thailand and Brazil provided they are covered.

The resistance to humidity is traditionally tested in immersion tests, i.e. the briquettes are dunked in water and the elongation or swelling of the briquettes is recorded. Sometimes the time elapsed until the briquette has completely disintegrated

One of the weakest points in briquette quality is that briquettes must not be subjected to water or humid air is taken as a measurement of the quality in this respect. This time can vary from a few minutes up to hours and again it is difficult to give an acceptable value for this parameter. In tests carried out by CRA, it has been found that the rate of elongation is a more precise parameter and they suggest that a figure of less than 50% elongation per minute indicates an acceptable quality.

In other tests, briquettes are subjected to humid air for extended periods and their swelling is recorded. After a period of 21 days in an atmosphere of 20° C and 95% humidity, an elongation of less than 30% is said to be acceptable and less than 20% would be ideal (CRA 1987).

Although resistance to humidity may not be such a crucial factor when storing briquettes, provided they are shielded from direct rain, this factor may be of importance in the combustion and, especially, gasification of briquettes.

Water vapour, driven off from inherent moisture and formed in combustion, creates a saturated climate at high temperatures which is a more fundamental test of a briquette's resistance to humidity. If the briquettes disintegrate too quickly, the loose substance will either elutriate un burned through the boiler or block the airflow to the process, depending on the circumstances. There are no good data on this though it does not usually seem to be a practical problem in combustion. It is possible however that such swelling and disintegration could be a bigger problem in the gasification of briquettes.

Combustion characteristics

Calorific value

One of the most important characteristics of a fuel is its calorific value, that is the amount of energy per kg it gives off when burned. Although briquettes, as with most solid fuels, are priced by weight or volume, market forces will eventually set the price of each fuel according to its energy content. However, the production cost of briquettes is independent of their calorific value as are the transportation and handling costs. The calorific value can thus be used to calculate the competitiveness of a processed fuel in a given market situation. There is a range of other factors, such as ease of handling, burning characteristics etc., which also influence the market value but calorific value is probably the most important factor.

Figure 8: Higher Calorific Value Diagramme

For quick reference, the calorific value of wood and most agro-residues can be calculated using the following formula which although originally derived for wood can be used for most agro-residues with little alteration:

Gross (or higher) calorific value (HCV) = 20.0 x (1 - A - M) MJ/kg where A is the ash content and M the moisture content of the actual fuel.

The lower (or net) calorific value, which takes into account unrecovered energy from the water vapour from inherent moisture and from the oxidation of the hydrogen content, is sometimes used for reference purposes, especially in industrial applications. In wood and most agroresidues, the hydrogen content is about 6% by weight on a dry and ash-free basis, which means that the above formula would be changed as follows:

Lower calorific value (LCV) = 18.7 x (1 A - M) - 2.5 x M

Example: Rice husk with a moisture content of 15% and an ash content of 20% has the following calorific values according to the above formulae:

HCV = 20.0 x (1 - 0.2 - 0.15) = 13.0 MJ/kg
LCV = 18.7 x (1 - 0.2 - 0.15) - 2.5 x 0.15 = 11.8 MJ/kg

For materials with low ash contents and moisture contents between 10% and 15%, that is most briquettes from wood and agroresidues, the resulting calorific values are found in the 17 - 18 MJ/kg range (LCV: 15.4 - 16.5 MJ/kg).

Table 2 (reprinted from Barnard, 85) gives an indication of the variations of ash content and calorific value for a number of agricultural residues. There are discrepancies in the calorific values from different sources, probably due to inaccurate testing procedures. Note that the HCV of an actual fuel has to be adjusted for moisture content using the above formula.

Table 2: Calorific Value and Ash Content of Verious Fuels. (Barnard 85)

Material	**Ash Content %**	**HCV MJ/kg (oven dry) (oven dry)**	**Material**	**Ash Content %**	**HCV MJ/kg**
Alfalfa straw	6.0	18.4	Olive pits	3.2	21.4
Almond shell	4.8	19.4	Pigeon pea stalks	2.0	18.6
Cassava stem	-	18.3	Rice straw	-	15.2
Coconut shell	0.8	20.1	"	19.2	15.0
Coconut husk	6.0	18.1	Rice husks	-	15.3
Cotton stalks	17.2	15.8	"	16.5	15.5
"	3.3	17.4	"	14.9	16.8
Groundnut shells	-	19.7	Soybean stalks	-	19.4
"	4.4	20.0	Soybean stalks	-	19.4
Maize stalks	6.4	18.2	Sunflower straw	-	21.0
"	3.4	16.7	Walnut shells	1.1	21.1
Maize cobs	1.5	18.9	Wheat straw	-	18.9
"	1.8	17.4	"	8.5	17.2

Combustion in industrial boilers

Experience shows that industrial boilers are usually the most convenient and accessible combustion plants for briquettes. Even so, the range of plants which can utilise briquettes directly are those designed for solid fuels, that is wood or coal. Oil plants can be converted to take solid fuel but only at considerable expense. This means that briquettes can only be readily marketed in the industrial sector in those countries where either coal or wood has an existing base.

The advantages which briquettes possess over the unprocessed residue in ease of handling and transport extend through to the combustion device. This means that most residues can be combusted more efficiently when briquetted even in those cases where the plant can actually handle unprocessed residue. This gain in efficiency may be enough on its own to justify briquetting though it is difficult to obtain accurate data in many circumstances.

The most common problems encountered in burning raw residues are the difficulty of actually feeding material into the plant and that, in the combustion zone, loose residues may blow around and not burn completely. Briquettes avoid both these problems.

There are no good data available on the loss of combustion efficiency in burning raw residue. In India, it was claimed that raw rice-husk showed a 20% drop in efficiency as against rice-husk briquettes, though this was not based on rigourous measurements.

The ease of feeding briquettes is usually an advantage over raw residues. However, in some cases, the raw material can be handled pneumatically (for example, rice husk and jute dust) which although expensive may be advantageous. In practice, the extent to which an industry is prepared to invest in equipment to enable raw residues to be handled and fed into the combustion plant may determine whedher or not briquetting has a role to play.

In Brazil, for example, a number of plants have installed the equipment necessary to combust baled bagasse, which is available in large quantities. There is therefore no incentive to briquette bagasse as it has an immediate outlet.

There is only limited room to generalise about the balance between converting the residue to a convenient form and converting the combustion equipment to burn residues directly. It is probable chat the bigger the plant the more likely chat plant conversion would be economic. However, the exact economics would be very sitespecific.

General experience suggests that briquettes are a good substitute for wood, possessing a consistent quality which can enable a price premium to be obtained over wood.

There are virtually no quantitative data on the combustion characteristics of briquettes in industrial plants whether boilers or various kinds of kilns. General experience suggests that they are a good substitute for wood, possessing a consistent quality which can enable a pricepremium to be obtained over wood. This is evident in Brazil where wood is often sold in variable qualities and quantities. It is also claimed that wood-based briquettes in Ghana are sold at higher prices than wood (World Bank 1987).

It is not dear whether such a premium extends to high-ash residues such as rice-husk. It might be expected that these would have more problems in substituting for wood. However, briquettes based on residues such as coffee-husk and groundnut shells appear to be virtually interchangeable with wood.

The substitution of briquettes for coal may be more problematic though the only source for comparisons at present is India where the usual residue, rice-husk, has an unusually high ash content In this case, briquettes can be burnt satisfactorily only in a limited range of coal appliances, for example step-furnaces. In other types, for example moving grates, the rice-husk briquettes can fall between gratebars before they are completely combusted.

It is also possible that in some coal appliances there could be problems with ash-slagging but no data are known to exist about this.

Combustion in household stoves

It appears that, in practice, briquettes are usually burnt in industry` However, much of the recent interest has been in using briquettes in households in countries where wood shortages and deforestation are problems. In this section, the suitability of briquettes in household stoves is discussed, though based on some very limited data.

Reports of laboratory work carried out in Europe tends to give a rather positive picture of the behaviour of briquettes in household stoves. Tests done at TNO in the Netherlands (Krist-Spit 1985) of six different briquette types in five stoves showed that the substitution of briquettes for woodfuel or charcoal would probably not be restricted by the combustion properties of the briquettes. Some differences between briquettes were observed, however. The Thai bucket stoves performed particularly well and showed thermal efficiencies between 33% and 46%.

They found that the combustion behaviour of briquettes is comparable to wood rather than charcoal The briquettes burn with somewhat higher flames and a little more smoke than charcoal However, the test report states that briquettes from rice-husks and mimosa, if the briquette diameter is small could be competitive to charcoal.

The TNO tests clearly showed that large diameter briquettes, especially when made from raw materials with high ash contents, such as rice-husk and water hyacinth, are unsuitable for domestic cooking purposes because the heat-rate is insufficient and they are difficult to ignite. This is not necessarily a problem of briquettes as such. Large diameter wood logs, comparable to the 8-10 cm diameter briquettes from large piston-presses, are seldom burnt uncut in household stoves.

In the experiments carried out at CRA in Gembloux (CRA 1987), briquettes were subjected to combustion tests in which the elongation during combustion was measured as well as the rate of weight loss. The times during which the combustion resulted in smoke, flames and glow were observed. The overall conclusions of this work can be summarized as follows: hard, dense briquettes swell very little or not at all during combustion, they have a slow rate of weight loss (i.e. they last a long while) and they burn without flames for a longer period as welt thus resembling the performance of charcoal.

For softer briquettes, the opposite is the case, i.e. they swell quickly and by doing so they start to crack up which increases the rate of mass loss and shortens the total combustion period. Such behaviour is particularly characteristic of hydraulic-piston briquettes.

Some of the materials, especially rubber wood, gave off a lot of smoke during the combustion tests which indicates that such briquettes are probably unsuitable for cooking stoves.

This data all comes from laboratory tests which are useful for basic analysis but may not cover all the factors which make a product acceptable in practice.

There are little good data about the potential acceptance of briquettes in household stoves in practice. Some limited market studies in Niger suggest that the laboratory-based results were sound and that briquettes are acceptable to domestic consumers. Recently, in the Sudan, several thousand tonnes of groundnut-shell briquettes, made in a large piston machine, were sold to domestic customers. They were reported as being quite happy with the combustion properties even though they often had to break up the briquettes.

Both the Niger and the Sudanese experience was that piston briquettes can be used in households though possibly in combination with wood fuel. This is corroborated by some limited experience from a plant located in Kigali, Ruanda.

In Thailand, there has been considerable experience of selling screw-briquettes to households made from both rice-husk and from wood residues. The rice-husk product seems problematic because of its ash content but can be burnt whilst wood-based briquettes are quite satisfactory. The problem of acceptability lay with price not quality.

There is also some experience in the use of charcoal-briquettes made by binding charred residue with molasses. The results are contradictory, something which may be related to the different cooking situations in which the briquettes were used.

In India, great problems were found in persuading households or small tea-shops to burn molasses-bound briquettes. There were complaints about smells and about the speed of burning when compared with charcoal or coal-briquettes.

In Sudan, on the other hand, some market research carried out on molasses-bound charcoal briquettes made from cotton stalks were said to be an acceptable charcoal substitute. The high ash content of the Indian briquettes may have been an inhibiting factor but this cannot account for the smell problem.

Gasification of briquettes

The gasification process places higher quality demands on the briquettes than does combustion. The fuel bed is thicker, adding to the weight load on the briquettes at the bottom while residence times are longer, during which the briquettes are subjected to humidity at elevated temperature. In a gasification plant mounted on a vehicle, the vibrations will add additional stresses on the fuel and increase the risk of blocking the gas flow.

There are a number of important potential advantages of using briquettes instead of for example chipped wood for gasification: the briquettes are drier, increasing the efficiency of the process and increasing the calorific value of the produced gas; the bulk density is higher, increasing the residence time in the gasifier and the gas conversion rate and, finally, the size of the briquettes can be chosen to fit together with the size of the gasifier and the gasifier grate.

In tests carried out by CRA, seven gasifiers, both mobile and stationary, were operated with briquettes made from different materials. The overall results were very good, though the high silica content in the rice-husk briquettes caused sintering and blockage of the gas flow.

In general it appears that briquettes could be used to provide a consistent feedstock to most gasification systems. However, very little data based on practical experiences are available.

Chapter 5.Economics of briquetting

The costs of briquetting depend upon a number of operating costs, including labour, maintenance, power, raw material cost and transport, and various other sundry charges, as well as a capital cost component.

Almost all the cost categories discussed above depend to a more or less significant degree either on accounting conventions (this is particularly relevant for the calculation of capital charges) or on-site or country specific factors. We have analysed capital charges using the assumption of a 10% interest charge on a 10-year loan, numbers which fit broadly the kind of loans made to plants which were visited.

Operating costs were analysed on the basis of actual plant experience, design studies and manufacturers' data. However, no allowance has been made for the cost of raw materials over and above transport charges. The country studies make it clear that where briquetting has become commercially viable to a degree there is a tendency for residues to acquire a market price where previously they were free.

The cost ranges derived for a large piston machine are:

	US $/t
Capital charge	9-12
Labour	3-5
Maintenance	3-8
Electricity	3-7
Raw material transport	1-4
Other	at least 1

A simple addition of the least and greatest costs would suggest that a piston-machine briquetting plant would have total factory costs in the range 20-36 US$/t of product.

It would however be misleading to adopt costs in the lower part of this range except under the most favourable circumstances; these might be the use of dry wood-waste drawn from the immediate locality in a country where labour costs and power prices are low and where fairly low-cost machinery is available. A possible location meeting these criteria is Brazil; there a company planning to set up a number of large briquetting plants in the interior has suggested that total costs would be about 26 US$/t including some payment for wood-wastes. This must represent very much the bottom end of the cost range.

In other, less favourably situated countries, it is much more likely that total costs would be towards the upper part of the range. It should be emphasised that these do not include any allowance for residues being priced nor for any profit element.

It would be expected that the unit costs for screw presses would be somewhat higher than for piston machines. They do not appear to offer any significant advantages in investment costs and in some cost categories, notably maintenance and power, they are likely to be more expensive. They also appear to have higher unit labour costs though this is probably a factor relating to scale of production rather than any intrinsic feature of screw presses.

The higher intrinsic costs of the screw machines may however be offset by the fact that their small production levels, and indeed small physical size, means that they can be, literally, squeezed into low-cost situations. These would typically be a small wood-plant able to site a machine right by the waste pile in a building which needs little or no modification.

One user in Kenya who has put a small screw press into such a favourable situation (except that it utilises residue from a nearby sawmill) has assessed total in house costs at about 21 US$/t including depreciation and finance. This includes no allowance for raw material transport costs and may underestimate power and maintenance costs. If these are corrected then it is likely that true factory costs are more like 25 US$/t.

In general, therefore, it would be wise to assume that total costs for briquette production are in excess of 30 US$/t and may be above 35 US$/t if some allowance is made for the cost of raw materials. Only in the most favourable circumstances would costs drop to 25 US$/t.

These numbers are in accordance with the situations in both Brazil and India, the two developing countries where briquetting has managed to establish some kind of commercial basis. In Brazil, it seems possible to survive by selling briquettes somewhere above 30 US$/t whilst in India a marketed price in excess of 40 US$/t is required. In both cases, these prices produce bare commercial survival rather than large profits. In India, it is common to pay up to 15 US$/t for rice-husk; in Brazil, wood-wastes are usually cheaper if charged at all.

These broad cost levels refer only to plants based upon factory residues. The costs for any field-residue plant will be much higher.

The economic viability of briquetting plants depends crucially on whether or not these factory costs are comparable or less than the prices of the main competitive fuel, usually wood but sometimes coal.

It is clear that in many countries the price of fuelwood is well below these levels to an extent that effectively rules out briquettes as commercial propositions. This is often true even if it is assumed that industrial consumers are prepared to pay a premium for briquettes as they are of consistent and reliable quality. Such premiums depend very much on the reliability of the local wood supply. In Kenya, no premium appears to be obtained while in Brazil it may be as much as 40%.

There are exceptions to this. It is reported (World Bank 1986) that fuelwood prices in Addis Ababa reached 83 US$/t in 1985; even allowing for a retail markup this allows considerable scope for briquettes to undercut fuelwood. However, industrial fuelwood prices in, for example, Kenya do not exceed 20 US$/t, a level which briquettes cannot hope to reach. Similar low fuelwood prices in Thailand have effectively destroyed the local briquetting industry despite very low investment costs and good raw material availability.

It is probably true that in most countries, the current level of fuel prices is too low to justify briquetting. Nevertheless the examples of Brazil and India show that it is quite possible for fuel prices to rise to levels where briquetting is viable. Such a rise can, moreover, take place quite rapidly: the fuelwood price in Addis Ababa was reported to be only 9 US$/t in 1973. It is likely that the price of fuelwood in the Sudan has now also reached the point where briquetting is competitive.

The key policy issue in many countries with respect to briquetting must be the judgement as to the extent to which it is worth supporting briquetting activities, in spite of their immediate lack of profits, in expectation that fuel prices will rise in the future. There is no general answer possible to this. There are many countries where fuelwood prices seem set to remain relatively low for the foreseeable future. Indeed in some countries there is genuine optimism about the possibility of stabilising prices indefinitely by the development of fuelwood plantations.

However, there are also countries where it seems likely that deforestation must cause a rise in prices in the not too distant future. In such circumstances briquetting of agro-residues can have a legitimate economic role without any need for subsidy.

Part 2.Briquetting technology

Chapter 6.An overview of the densification process

Densification essentially involves two parts; the compaction under pressure of loose material to reduce its volume and to agglomerate the material so that the product remains in the compressed state. The resulting solid is called a briquette if, roughly, it has a diameter greater than 30 mm. Smaller sizes are normally termed pellets though the distinction is arbitrary. The process of producing pellets is also different from the typical briquetting processes; a more detailed description will be given later in this section.

If the material is compacted with low to moderate pressure (0.2-5 MPa), then the space between particles is reduced. Increasing the pressure will, at a certain stage particular to each material, collapse the cell walls of the cellulose constituent; thus approaching the physical, or dry mass, density of the material. The pressures required to achieve such high densities are typically 100 MPa plus. This process of compaction is entirely related to the pressure exerted on the material and its physical characteristics.

The reduction of material density is the reason for undertaking briquetting as it determines both the savings in transport and handling costs and any improvement in combustion efficiency over the original material. The ultimate density of a briquette will depend to some extent on a range of factors including, most importantly, the nature of the original material and the machine used and its operating condition as well as other minor factors. However, the ultimate apparent density of a briquette from nearly all materials is to a rough approximation constant; it will normally vary between 1 200-1 400 kg/m^3 for high pressure processes. Lower densities can result from densification in presses using hydraulic pistons or during the start-up period of mechanical piston presses (which can last several minutes) whilst even higher densities are sometimes achieved in pellet presses. The ultimate limit is for most materials between 1 4501 500 kg/m^3. The relation between compression pressure, briquetting process and the resulting density of the briquette is illustrated in figure 9 (Bossel, 1984).

The apparent density of briquette will be higher than its bulk or packing density as the briquettes will not pack perfectly. The usual reduction would be a factor of roughly 2 depending on the size and shape of the briquette; that is bulk densities of 600-700 kg/m^3 are usual, sometimes a little less.

The bulk density of the original material may be difficult to define accurately, particularly in the case of materials like straw which are very easy to compress even manually. The lowest bulk densities are around 40 kg/m^3 for loose straw and bagasse up to the highest levels of 250 kg/m^3 for some wood residues. Thus gains in bulk densities of 2-10 times can be expected from densification. Since the material also will have to be dried in order to facilitate briquetting, the resulting increase in energy content per volume unit can be large compared to the raw materials.

A binding agent is necessary to prevent the compressed material from springing back and eventually returning to its original form. This agent can either be added to the process or, when compressing ligneous material, be part of the material itself in the form of lignin. Lignin, or sulphuric lignin, is a constituent in most agricultural residues. It can be defined as a thermo plastic polymer, which begins to soften at temperatures above 100°C and is flowing at higher temperatures. The softening of lignin and its subsequent cooling while the material is still under pressure, is the key factor in high pressure briquetting. It is a physico-chemical process related largely to the temperature reached in the briquetting process and the amount of lignin in the original material. The temperature in many machines is closely related to the pressure though in some, external heat is applied. There are thus two immediate ways of classifying briquetting processes:

Gains in bulk densities of 210 times can be expected when briquetting biomass.

1) High, intermediate or low pressure: this distinction is, in principle, dependent on the material used but the following rough classification may be adopted:

Figure 9: The Relation between Pressure and Density

Low pressure up to 5 MPa
Intermediate pressure 5-100 MPa
High pressure above 100 MPa

2) Whether or not an external binding agent must be added to agglomerate the compressed material. Usually high pressure processes will release sufficient lignin to agglomerate the briquette though this may not be true for all for all materials. Intermediate pressure machines may or may not require binders, depending upon the material whilst low-pressure machines invariably require binders.

A further classification is based upon the technology used to compress the biomass. This includes:

FIGURE A) Piston presses

In these, pressure is applied discontinuously by the action of a piston on material packed into a cylinder. They may have a mechanical coupling and fly wheel or utilise hydraulic action on the piston.

In these, pressure is applied continuously by passing the material through a screw with diminishing volume. There are cylindrical screws with or without external heating of the die and conical screws. Units with twin screws are also made.

In these, rollers run over a perforated surface and the material is pushed into a hole each time a roller pass over. The dies are either made out of rings or disks though other configurations are possible.

The above list is by no means comprehensive and there exist several other types of briquetting presses, especially in the low-pressure and low-capacity range.

Various types of roller-presses are also utilised to form briquettes, especially in making charcoal briquettes, from carbonized material. A binding agent must be employed in these and the process is more one of agglomeration than densification as there is only a limited reduction of volume.

FIGURE B) Screw extruders

FIGURE C) Pellet presses

FIGURE D) The roller-presses

Chapter 7.Mechanical piston presses

Main features

A reciprocating piston pushes the material into a tapered die where it is compacted and adheres against the material remaining in the die from the previous stroke. A controlled expansion and cooling of the continuous briquette is allowed in a section following the actual die. The briquette leaving this section is still relatively warm and fragile and needs a further length of cooling track before it can be broken into pieces of the desired length.

Figure 10: Piston Briquetter

In mechanical systems, the piston gets its reciprocating action by being mounted eccentrically on a crank-shaft with a flywheel. The shaft, piston rod and the guide for the rod are held in an oil-bath. The moving parts are mounted within a very sturdy frame capable of absorbing the very high forces acting during the compression stroke.

The most common drive of the flywheel is an electric motor geared down through a belt coupling. A direct-drive system using an internal-combustion or steam engine is possible and would not change the basic design of the briquetting machine.

Pressure build-up

The piston top is normally shaped with a protruding half-spherical section in order to get better adherence of the newly compressed material to that formed in the previous stroke. The most common type of briquette press features a cylindric piston and die with a diameter ranging from 40125 mm. The die tapers somewhat towards the middle and then increases again before the end. The exact form of the taper varies between machines and biomass feedstock and is a key factor in determining the functioning of the process and the resulting briquette quality.

The tapering of the dies can, in several designs, be adjusted during operation by means of narrowing a slot in the cylinder. This is achieved by either screw or hydraulic action.

One manufacturer (Krupp) uses a rectangular ram section. This allows for adjustment by narrowing the height or the width of the die.

The optimum tapering, and thus pressure, depends on the material to be compressed.

It can sometimes be enough to choose a nonadjustable die when the material is well defined and known to the operator. Changes in material composition, for example its moisture content, is a reason why it is useful to the operator to be able to adjust the compression continuously. However, in many operating plants in developing countries, machines with fixed dies are used. The main India and Brazilian manufactures produce only fixed die machines though most European suppliers have some die control. In adjustable systems, it is up to the individual machine operator to find the correct setting of the die as no automatic control systems has yet been introduced on the market. Developments are under way towards such automatic systems.

The use of proper taper for a given material feed is an important part of machine operation. It is clear that the attempt to do this on a trial and error basis rather than with the help of the manufacturer has often been a source of poor plant performance in developing countries. The closer liaison possible between user and manufacturer is a reason why domestically produced machines often show better performance than imported.

The pressure in the compression section is in the order of 110 to 140 MPa. This pressure, together with the frictional heat from the die walls, is in most cases enough to bring the material temperature up to levels where the lignin is becoming fluid and can act as a binder to produce a stable briquette. In fact, heat needs to be extracted from the process to prevent overheating. This is done by water-cooling the die.

The closer liason between user and manufacturer is a reason why domestically produced machines often show better performance than imported.

Machine capacity

The capacity of a piston press is defined by the volume of material that can be fed in front of the piston before each stroke and the number of strokes per unit of time. Capacity by weight is then dependent on the density of the material before compression. Thus although the nature of the original material does not markedly alter the physical characteristics of the briquette, it does have a major impact upon the practical output of a machine.

The feed mechanism is crucial and most manufacturers feature a proprietary design. By means of screws or other devices, they try to pre-compress the material in order to get as efficient filling as possible. This is particularly important when using materials whose bulk density is low and which need efficient feeding to achieve reasonable output. Substantial aerating of the "name plate" capacity may occur for agro-residues as most manufacturers rate their machines on a saw-dust feed, one of the denser raw materials.

The feed mechanism can, if badly mismatched with the feedstock, cause serious problems in machine operation. If undersized, voids may occur in front of the piston causing damage to the mechanism. The feeder itself may also jam if it is oversized and tries to move too much material into the piston space.

The need to have an efficient feed-mechanism suitable for a particular residue is the main reason why it is important to buy designs which have actual operating experience with that residue. Most machines can produce some briquettes of acceptable quality with virtually any residue. However the continuous production of briquettes at a reasonable capacity may not be so easy.

The design parameters of piston machines such as flywheel size and speed, crankshaft size and piston stroke length, are highly constrained by material and operating factors. In practice, the output of a machine is closely related its die diameter, as shown in Fig. 12 which contains data drawn from a large number of manufacturers specifications. Part of the variability of Fig. 12 is accounted for by the different bulk densities of the raw material assumed by manufacturers so the relationship for a standard material would be even closer.

Figure 12 shows that for estimating purposes an approximation of 18.5 kg/h/cm² can be assumed achievable during sustained operation of a mechanical piston press when the raw material is wood. With other raw materials of lower bulk density, the actual production capacity can be much less. One manufacturer offers the data shown in Table 3 for the variations between materials.

There is a shortage of data about the capacities of machines when used with different raw materials which reflects the limited experience which has been obtained outside of various wood-wastes. Table 3 shows an estimate, derived from manufacturers data, of how less dense materials have a lower capacity index relative to wood.

It is likely that consumer acceptance of briquettes is partly related to their size. A household user, for example, cooking on a open fire would be unlikely to accept a 10 cm diameter briquette any more than a 10 cm piece of wood. Briquettes can be split or broken but this may not be accepted by the consumer and, with soft briquettes, may lead to crumbling. Industrial customers may, on the other hand, be happy to accept large whole briquettes as these conform to their usual wood sizes. This means that in designing plants to receive certain residue volumes, some attention has to be paid to the intended market in deciding, for example, on the number of machines to be used.

Fig 12: Capacity versus Area of Mechanical Piston Presses

Table 3: Production Capacity Variation between Materials

Raw material	Bulk density kg/m³	Capacity index	Energy Index
Wood	150	100	100
Shavings	100-110	80	95
Groundnut shells	120-130	90	100

Capital investments in machinery

Most of the models represented in this study are manufactured in high-cost countries such as Switzerland, West Germany, Sweden and Denmark and are equipped for customers in these countries. This means, in plain language, that they are relatively expensive.

A range of manufacturers estimates for single machines has been obtained, though for fewer examples, and this data, shown in Figure 13 allows for a rough assumption of 1 500 US$/cm² (in 1987 prices). This, together with the capacity estimate above, results in a cost/capacity figure for preliminary estimates of 85 US$/kg/h which is consistent with the figures by other researchers (Kbinsky 1986).

Naturally there are technical differences between the models which ought to reflect the variations in costs between them. However, the 85 US$/kg/h represents the average ex-works price for a European press when applied to wood waste, with appropriate adjustment for aerating using other materials.

Prices quoted by manufacturers in developing countries, in particular, are much lower. The Brazilian manufacturer, Biomax, has a published price-list with machines costing only 3038 US$/kg/h for sizes between 450 and 2 200 kg/in. The price reduction appears to be achieved by a combination of machine simplification and lower labour costs. The main Indian manufacturer, Ameteep, also offer machines at prices lower than European manufacturers though less spectacularly than Biomax.

Figure 13: Cost of Piston Briquetters versus Die Area

The cost reduction achieved by machine simplification are not easy to define but they seem to relate, essentially, to the construction of a unit which requires rather more operator attention than European machines which are often left unattended for several hours. The die size is usually fixed, which means that there is less flexibility in feed variations. However as most plants work with a single feed it is not clear how restrictive this is in practice.

As few plants in developing countries ever need an unattended operation, it is clear that there is likely to be considerable scope for manufacturers to produce cheaper machines for this particular market. However, at the moment the small size of this market and its fragmented nature means that there is very little incentive to do this.

The cost of a basic mechanical piston press can be assumed to 85 US$/kg/h for preliminary estimates.

Maintenance and spare parts

Being robust heavily-built machines, piston presses have long technical lives and they need limited daily service. The main wear parts are the die, piston-head and tapered cylinder. The service lives given by manufacturers for these pars are in the order of 500 to 1000 hours which may be true for clean, non-abrasive materials such as newly chipped wood. Most other materials are less friendly, resulting in shorter service lives of the wear parts.

The prices given by European manufacturers for individual spare parts are given in the Table 4.

This data is not consistent since the various manufacturers have different designs in which each individual piece has different service life. The die itself is subjected to most wear and has often to be exchanged twice as often as the other parts.

Average costs estimates for maintenance offered by the manufacturers also vary widely. One source gives the following figures for cost par annum as a percentage of original investment:

Table 4: Costs of Spare Parts for Piston Machines

	Diameter of the die (mm)			
	40	55	75	125
Part	US$			
Die	130	217	190	525
Cylinder	230	250	500	1 315
Piston	120	105	550	985

Sawdust: 2%
Groundnut shells: 3%
Straw: 5%

Another manufacturer offers the estimate of 3.3 US$/ton product for wood-waste. When briquetting groundnut shells the wear part costs increases to 5.3. $/ton and with waste paper it can go up to 7.9 US$/ton.

Field data of maintenance costs in the case of piston presses have been reported by Overseas Development Natural Resources Institute (ODORI 19887). These confirm the general anticipation that, when operating with an abrasive raw material such as rice husks, the wear of the die piston becomes a severe problem. The service life is reduced to about 70 hours and even if reboring and build-up welding is possible, spare parts will have to be bought several times a year. This became problematic in one of the Indian projects, using a European manufactured press, due to the high prices of the spares and foreign exchange problems plus costs for shipping and import duties.

In the case of locally manufactured machines and spare parts. these problems are not as severe. The price for a 90 mm replacement die is reported to be 2 0003 000 rupees (160-240 US$) which is broadly the same prices reported by European manufacturers but can be paid in local currency and is easily available. One Indian plant has resorted to making its own replacement dies at a local engineering plant following problems with obtaining spare parts. This suggests that the technical problems are not large though the plant owner in this case is a qualified engineer.

An Indian project operating with a mixture of coffee husks and groundnut shells is reported to change die 3 times a year which is equivalent to a service life in the order of 1 300 hours, though intermediate reboring of the die takes place every 200 hours. The resulting maintenance costs (ODNRI 87) are 88 rupees per ton (7 US$/t) for rice husks and 31 R/ton (2.5 US$/t) for the mixture of coffee husks and groundnut shells.

Both manufactures data and operational experience suggest therefore that maintenance costs are likely to be in the range of 3-8 US$/tonne of product with the higher values referring to more abrasive residues such as rice-husks.

Energy costs

Energy costs in briquetting are made up of three separate effects: the losses in the machine moving parts (which are effectively negligible in this context), the frictional losses between the material particles when compressed and the frictional losses between the material and the walls of the press.

The frictional losses between the material particles are essentially constant for a given ultimate density and material and, given that most briquettes have much the same density, is probably roughly constant for all briquettes. Material differences will occur but should not be large.

The major variable element is undoubtedly friction between the briquette-material and the machine and here the larger the diameter the less will be the unit energy losses as the surface areas increase by a lower factor than the die volume.

The standard piston-press is equipped with an electric 3-phase motor which drives the flywheel via a V-belt (sometimes a flat belt). Motor capacity is designed with a safety margin for the promised output. Manufacturers claim that actual power consumption is 60-80% of the installed power of the main drive. To this figure should be added the power consumption of the feeder which for most models lies in a 10-20% range of the main drive motor .Thus for calculations one can assume that the main drive and feeder motor consume power equivalent to the rating of the main motor. This power rate is plotted against the die-area in Figure 14 for a standard woodresidue feed.

This shows a wider spread of data than in the case of capacity vs area (Fig 12) which is not surprising since the manufacturers obviously have the choice of installing as much power as they feel necessary to give an adequate safety margin. It is still possible to derive a curve-fit that could be used for preliminary studies. We suggest the following estimates which are valid for wood-waste"

$P(kW) = 4*(A)^{2/3}$
where A is the diameter in cm^2

This corresponds to:
$P(kW) = 0.58*(Q)^{2/3}$
Q is capacity in kg/in

When the rate of production (or the diameter) is known it is possible, using this relation, to calculate the energy consumption per ton of output. For example, it takes 58 kWh to produce 1 ton in a 1 000 kg/in machine whilst at 500 kg/in output the same quantity demands 73 kWh. There is thus an overall saving in moving to higher throughputs and to larger briquettes. These formulas are not verified in laboratory tests and should not be used for designing briquetting plants. They can however serve in economic feasibility calculations and when checking if a given data is of the right order of magnitude.

Figure 14: Power Requirements of Mechanical Piston Presses

The variations in energy requirements between different materials can be quite large. One manufacturer gives the estimates presented in Table 5.

Differences in material moisture content can cause even higher variations in energy requirements than those between materials. The drier the material, the higher is the friction loss. This factor limits the lower end of the moisture content range acceptable in presses. With dry materials it can be necessary to condition the material with water or steam prior to the densification, though this is more often seen in pelleting operations.

A complete and fully automated plant will contain a number of electric-motors for disintegrating the raw material and product handling and transportation. The energy demand for these drives will have to be evaluated from case to case. In many overseas plants the handling will be done by hand although there may still be needs for material treatment such as chipping.

Raw material quality demands

The mechanical piston press was developed and has found most widespread use for the briquetting of dry woodwaste. A typical user is a European sawmill or joinery feeding shavings, planings, sawdust or bark to be briquetted either for internal use in solid-fuel boiler or for sale to nearby customers.

Because of the high pressure build-up, the piston press can only density dry material. If it is moist, the steam generated during the compression, will at best crack the surface of the briquette when the pressure is released after the cooling cylinder. At worst a sudden increase of the moisture content of the feed can cause a steam explosion within the cylinder which will expel the briquette violently and damage the machine. An accident in Turkey where the whole machine had to be replaced due to the briquetting of excessively wet material has been reported. (ODNRI 1987)

The moisture limit in most cases is 15% though some material with up to 20% can be densified in a piston press. The ideal operating region in respect of moisture content is 8-12%. With drier material the friction and thus energy demand increases and the lower limit is about 5%.

Table 5: Variations in Energy Needs for Different Materials

Material	**Capacity kg/h**	**Energy need kW**	**Product density kg/m³**
Model A			
Wood	600	32	1200
Groundnut			
shells	500	17	1100
Straw	500	25	1000
Model B			
Wood	1500	45	1200
Groundnuts	1500	40	1100

These moisture limitations means that before briquetting wet material, it has to be dried. The capital cost of a drier can often double the plant investment required as well as increasing the operating costs.

Another quality aspect is the size of the raw material. Ideally the material should contain both long and short fibres with the maximum particle size depending on material and diameter of the die. Larger machines can accommodate large particle sizes in the range of 8-10 mm with allowance of up to 15 mm for a die diameter of 125 mm.

As has already been discussed, different materials result in fairly large variations in capacity, energy consumption and maintenance costs. In terms of briquette quality however, most ligno-cellulose material within the above moisture and fraction limits can be briquetted with acceptable results in a mechanical piston press. It is the most versatile process available and its use is largely limited by the investment costs.

The main quality problem with piston briquettes is that the material is built up in the form of thin disks corresponding to the volume of residue compacted in each piston stroke. These disks form the natural line of cleavage across the briquette and, if the material does not adhere adequately, the briquette can break up into these smaller disks.

The mechanical piston press can only densify material only densify material with less than 15 % moisture consent.

This is not necessarily a disadvantage. Indeed it may be the best way for large diameter briquettes to be broken up into pieces suitable for household use. This is also the practice in industrial application in Sweden, where the broken briquettes are better suited for automated transportation equipment.

However, if the briquettes are too soft, such splitting can be the first stage of complete disintegration.

Materials known to have been used as raw material in commercial or demonstration projects with mechanical piston presses are listed in Table 6.

Table 6: Materials Used in Mechanical Piston Presses

Bagasse	**Groundnut shells**	**Straw**	**Cotton stalks**
Cotton waste	Cacao shells	Tobacco waste	Pineapple waste
Maize waste	Rice husks	Wood waste	Sawdust and shavings
Bark	Peat	Olive bagasse	Skins of grapes
Metal Waste	Sunflower pits	Cork Waste	Brown coal
Hemp waste	Coal dust	Pencil waste	Lignin

The normal procedure when studying the detailed feasibility of briquetting project is to send samples of the product to potential vendors who will carry out test pressings. The outcome of these tests will tell both parties something of the product quality they can expect in full scale operation and give a lower limit of the capacity of the machine. As discussed above, material tests should cover not only briquette quality but the ability of the feed mechanism to cope with adequate throughput of residue.

Such testing will not say very much about service life of wear parts and the vendors will, for materials not very well known to them, be unlikely to give any guarantees with respect to maintenance costs.

Chapter 8.Hydraulic piston presses

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Main features

The principle of operation is basically the same as with the mechanical piston press. The difference is that the energy to the piston is transmitted from an electric motor via a high pressure hydraulic oil system. In this way, the machine can be made very compact and light, since the forces are balanced-out in the press-cylinder and not through the frame. The material is fed in front of the press cylinder by a feeding cylinder (a so called press-dog) which often pre-compacts the material with several strokes before the main cylinder is pressurized. The whole operation is controlled by a programme which can be altered depending on the input material and desired product quality. The speed of the press cylinder is much slower with hydraulic press action than with mechanical which results in markedly lower outputs.

The briquetting pressures are considerably lower with hydraulic presses than with mechanical systems. The reason is the limitations in pressure in the hydraulic system, which is normally limited to 30 MPa. The piston head can exert a higher pressure when it is of a smaller diameter than the hydraulic cylinder, but the gearing up of pressure in commercial applications is modest. The resulting product densities will normally be less than 1 000 kg/m³ and durability and shock resistance will naturally suffer compared to the mechanical press.

Capacity

Capacity data do not show the consistency of the data for the mechanical press. For a given diameter, a manufacturer can specify a range of output depending on the size of the installed motor. With a couple of exceptions, most manufacturers have models with rated capacities in the range of 40 to -135 kg/in, though units can be obtained up to 800 kg/in output. It is this ability to operate at low output levels which is the main attraction of hydraulic piston machines. Essentially they extend the mechanical piston press output down to the levels of the screw press.

Capital investment

It might be expected, on general grounds, that hydraulic units would be cheaper than mechanical presses, given the lower stresses and pressures to which the machines are subject. Comparisons are difficult as the size ranges are rather different but where they overlap it appears that in practice, prices are on an equal level. The machine costs reported by Kubinsky (Kubinsky 1986) also show specific prices in the 100 to 200 US$/kg/h range which makes them as expensive as the mechanical presses for the same sizes.

Raw material quality demands

The use of a lower briquetting pressure means that the hydraulic press can tolerate somewhat hither moisture contents compared to the mechanical press. Figures between 15 and 35 % are given by manufacturers. However, even if the moisture tolerance differs between the raw materials, it seem doubtful that it is possible to successfully produce durable briquettes with raw-material moisture much higher than 20 %.

It is also likely that even if higher moisture contents can tee tolerated in the press, organic material would have to be dried after briquetting if long storage times are planned.

General discussion

Only one project with a hydraulic piston press in developing countries has been identified operating in Kenya on a mixture of coffee husk and sawdust. The experience there is that operation has been riddled with trouble and that the machine required frequent service. Spare parts were originally imported but since this proved too expensive they are now manufactured locally.

These problems maybe a function of particular circumstance but the briquettes produced in the plant were certainly soft and of poorer quality than those from a screw press also installed. In general the product made in hydraulic presses have significantly lower densities than those made in mechanical presses, making it doubtful that they are suitable in developing country projects where the briquettes need to endure long transportation and storage times. They can possibly be considered when looking for a small briquetting machine which makes briquettes for in-house use, though the screw-presses are highly competitive in this size range.

Chapter 9.Screw presses

Overview

These machines operate by continuously forcing material into a die with a feeder screw. Pressure is built up along the screw rather than in a single zone as in the piston machines. Three types of screw presses are found on the market. They are: conical screw presses; cylindrical screw presses with heated dies and ditto without externally heated dies.

Only one manufacturer is currently marketing the conical screw press, Biomass Development Europe (BMD) in Belgium. Cylindrical screw presses are manufactured by 3 manufacturers included in our study while 9 companies have been identified which manufacture the heated die type of extrudes, originally of Japanese design.

ATS in Switzerland manufacture a twin type of screw extruder with a patented design allowing for the direct densification of moist materials. Drying takes place internally in the machine from the frictional heat developed in the process. A system of funnels allows the generated steam to escape from the material and the process can accept raw materials with moisture contents up to 35 %. The energy for the drying will have to be supplied through the mechanical power drive which means that the electric motors are oversized when compared to processes densifying dry material. No presses of this design have so far found utilization in developing countries. In our view, the higher energy costs for drying with electricity compared to fuel or solar drying, plus the difficulties envisioned in installing the large motor drives in weak electricity grids, will make such application unlikely.

Figure 16: screw press with heated die

Conical screw presses

Although this is originally an American design, the only current manufacture appears to be BMD in Europe. They manufacture one model with a claimed capacity of 600 to 1000 kg/in. It features a screw with a compression die-head of a patented design. It is reinforced with hard metal inlays to resist the very high wear experienced with this type of extrudes, especially when briquetting abrasive materials. The die is either a single hole matrix with a diameter of 95 mm or a multiple 28 mm matrix. The briquetting pressure is 60 to 100 MPa and the claimed density of the product is 1 200 -1 400 kg/m³.

The machine is equipped with a 74/100 kW 2-speed motor. Assuming a total of 100 kW for a production rate of 1000 kg/in one arrives at a specific energy consumption of 0.10 kW/kg/h. The manufacturer claims that the actual average energy demand is 0.055-0.075 kW/kg/h. A piston press with the same output demand 0.058kW/kg/h according to the formula derived above.

The price of the machine is US$ 130 000 which corresponds to 130 US$/kg/h using the higher capacity given by the manufacturer.

The mixing and mechanical working of the material in the conical screw press is undoubtedly beneficial to the quality of the product. Continuous operation also aids quality as the briquettes produced do not have the natural cleavage lines as is the case with piston briquettes. This is generally true for all types of screw presses.

The main disadvantage is the severe wear of the die head and die which results in high maintenance costs. The die head of the BMD unit was originally made in hardened steel which gave acceptable results when briquetting wood. Trials with groundnut shells showed alarmingly high wear which led to the redesign of the diehead using carbide inlays. The costs foor the snare parts are:

	US$
Die head	1 300
Conical Screw	3 100
Die	1 600
Cone	2 300
Cylinder head	3 400

Figure 17: Conical Screw Press

The service life of the die head is said to be:

- With groundnut shells 100h
- With rice husks (estimated) 300h

Total costs for wear parts when briquetting groundnut shells are said to be 13.8 US$/t. This is two to three times the cost level given for piston presses briquetting the same material. The most serious part of that is that the die head, having to be imported from the manufacturer since the manufacture with carbide inlays requires a special workshop.

The experience with this model, apart from the apparently widespread use of its predecessor in USA, is restricted to two projects, one operating on groundnut shells in USA and another in France operating with wood as raw material. There are some ambitious plans to operate BMD machines in Brazil and Argentina in large multi-unit plants based on saw-mill residues.

Screw extruders without die heating

In this category we have included one European and one Asian manufacturer. Kusters Venlo-Holland of the Netherlands have developed a multiple hole matrix screw extruder for densifying chicken manure. It is a low-pressure process and the manufacturer gives a lower limit of the moisture content at 30 %. The manure is compressed to reduce its volume by half and the product is air dried after compression to be used as a boiler fuel.

The capacity of the machine is 300 kg/in (wet basis) and the price of the unit is US$47 300. The rated power of the installed motor is 22/30 kW. No data is available for maintenance costs.

A similar, though very much simplified machine, is the model developed by Prof Watna Stienswat of Kasetsart University in Thailand and manufactured by Sai Kampangsaen Motors. It is a screw extruder for wet materials (40-50%) with a capacity of 4 ton/day (wet basis) or 500 kg/in. It features a 5 kW motor driving a screw which is rotating with 800 rpm. The cost of the machine is US$730 and a replacement screw costs US$73.

The screw need new threads welded on after about 65 ton of produced briquettes at a cost of US$8. The manufacturer claims to have sold 40 units in two years time and the buyers are said to be farmers and hobby briquette producers. It is handfed and works best with slightly decayed bagasse. The product is very soft and must be placed by hand on the trays used for airdrying. The machine is of limited applicability but, in the right circumstances, may be a low-cost route to briquetting.

Screw extruders with heated dies

This type of extruder has found a number of applications and is manufactured not only in Japan, where it was originally developed, but also in Taiwan, Thailand, Austria and now also in Luxembourg, thanks to technical development work by CRA of Belgium.

The main features of this type of press is a screw which feeds the material from a feeding funnel, compacts it and presses it into a die of a square, hexagonal or octagonal cross-section. The briquettes have a characteristic hole through the centre from the central screw drive. The die is heated, most commonly by an electric resistance heater wired around the die. One press, Wacon of Taiwan, operates with both a 2kW preheater mounted on the chute below the feeding bin plus a 4 kW heated die.

The process can be controlled by altering the temperature. The normal operating temperature is in the order of 250 - 300 °C. The central hole of the briquette will act as a chimney for the steam generated due to the high temperatures in the process. An exhaust is normally mounted above the exit hole from the mould where the briquettes are cut into suitable lengths. A reduction in moisture content is thus achieved during the formation of the briquettes by a couple of percentage points.

The pressure is relatively high which, combined with the high temperatures, limits the moisture content of the raw material to be used. The actual maximum depends of the raw material but is in the order of 15 - 20 %. When briquetting a wet material such as saw-dust, the Japanese manufacturers include a suspension dryer in the system, which brings the moisture content down to 10 %. The resulting product will have a final moisture content of 7 %.

Most models produce a briquette with a diameter of 55 mm and an inner hole diameter of 15 to 25 mm. Variations of the outside diameters between 40 and 75 mm can be found. A common capacity given by the manufacturers of a 55 mm machine is 180 kg/h for wood material and 150 kg/in for rice husk. Variations exist due to differences in screw design and speed.

The energy demand is consistent with these variations in capacity, ranging from 10 kW for a 75 kg/in machine to 15 kW for a 150 kg/in, both based on rice-husk briquettes. To this should be added the 3 to 6 kW of electricity that is used for heating the mould. Assuming the total of 18 kW for a 150 kg/in machine, this results in a specific energy demand of 0.12 kWh/kg. A mechanical piston press would theoretically (such small machines are not made) have about the same energy demand. This level of power consumption is confirmed by the operational results of a plant in Ghana which operates four 150 kg/in screw-presses. Here, the reported power consumption is 0.11 kWh/kg (World Bank 1987).

Both Shimanda and PINI+KAY market machines with larger outputs in the range of 400-800 kg/in. They are equipped with 45 kW motors and PINI+KAY specifies an electric heater of 6 kW. Using an average figure of 600 kg/in and 50 KW the specific consumption is 0.083 kWh/kg for this size of screw press which can be compared with the corresponding figure of 0.069 kWh/kg for a mechanical piston press. The difference is not significant and is not verified in experiments.

Thus although one would expect screw presses to have higher power consumption than piston units, the practical differences do not appear to be large. Screw extruders produce good quality briquettes. The high maintenance costs are a drawback.

The capital cost of the screw presses varies widely with the country of origin. The specific prices range from 20-40 US$/kg/h for a Thai machine to 155 US$/kg/h for a Japanese screw extruder with similar features and output. Though there are large differences between manufacturers capabilities in fulfilling and following up an international contract for delivering such machines, especially when it involves setting up a whole fuel making plant, the figures show that it is possible to manufacture functional machines in a developing country, at least for the local market, at prices well below European or Japanese prices.

An estimate of the total cost for a 2 400 t/a rice husk briquetting plant in Thailand is of the order of 30 000 US$. This sum can be compared with one manufacturers estimate of the equipment cost for a 1 600 t/a briquetting plant delivered from Japan to Africa. Including a rotary drier, two briquetters, sieves, conveyors and spares for 3 years operation, the CIF price came to US$193 000.

The same large differences can be found when looking at maintenance costs, but going in the opposite direction. A Thai briquette factory has one welder for each of the three shifts constantly welding new threads on the screws. The screws need building-up and redressing every 100 hours whilst the dies will have to be rebored every 500 hours and exchanged every 1 000 hours. The Thai manufacturers own estimate of the maintenance cost is equivalent to 14 US$/t, which is the most expensive single item in the production. (Some element of depreciation cost may have been built into this aggregate figure).

On the other end of the scale, the Japanese manufacturer in the above mentioned example estimated that the spare parts necessary for 3 years operation comes to the equivalent of 1.5 US$/t. In the Kenyan project included in our case studies, the maintenance costs for a Taiwanese screw extruder operating on sawdust is given as the equivalent of 4.2 US$/t. This cost is regarded as being excessive by the operators of the plant and a reason for taking it out of service.

The statistical data is limited but it appears that the operation or screw extruders generally results in somewhat higher maintenance costs than with piston presses, when briquetting the same raw material. This means that economic operation in developing countries is, to a higher degree than for piston presses, dependent on local manufacturers of spare parts and availability of skilled service engineers.

The screw extruders produce good quality briquettes which can be handled, transported and stored without any major problems. One example of this is a Thai producer, who, with equipment manufactured by himself, partly from used car parts, makes solid briquettes from rice husks that can withstand a 650 km truck ride to the consumers.

Screw extruders were originally developed and used for briquetting sawdust. The field data verifies that this type of machine also work well when briquetting rice husks, apart from the high wear problems. The African case involved the briquetting of coffee husks in a screw extruder which resulted in reasonable quality of the product when the husk was mixed with sawdust. The following is a list of material which manufacturers claim their machine are not have been briquetting.

Wood chips	**Saw dust**
Rice husk	Groundnut shells
Bagasse	Cornstalks
Sugar cane tops	Wheat husks
Coffee husks	Bark
Coir dust	Papermill sludge

Based on claims by manufacturers on the number of machines produced (one reports over 600 units sold) and reported use in Asia, screw extruders probably outnumber piston presses if counting the existing units on the market. They can be manufactured at lower costs than piston presses and at a less advanced engineering level. The main drawback seems to be the high maintenance cost, especially when operating on abrasive materials.

Chapter 10.Pellet presses

Overview

Pellets are the result of a process which is closely related to the briquetting processes described above. The main difference is that the dies have smaller diameters (usually up to approx. 30 mm) and each machine has a number of dies arranged as holes bored in a thick steel disk or ring. The material is forced into the dies by means of rollers (normally two or three) moving over the surface on which the raw material is distributed.

The pressure is built up by the compression of this layer of material as the roller moves perpendicular to the centreline of the dies. Thus the main force applied results in shear stresses in the material which often is favourable to the final quality of the pellets. The velocity of compression is also markedly slower when compared to piston presses which means that air locked into the material is given ample time to escape and that the length of the die (i.e. the thickness of the disk or ring) can be made shorter while still allowing for sufficient retention time under pressure.

The pellets will still be hot when leaving the dies, where they are cut to lengths normally about one or two times the diameter. Successful operation demands that a rather elaborate cooling system is arranged after the densification process.

Main features

There are two main types of pellet presses: flat and ring types.

The flat die type have a circular perforated disk on which two or more rollers rotate with speeds of about 2-3 m/s which means that each individual hole is overrun by a roller several times per second. The disks have diameters ranging from about 300 mm up to 1 500 mm. The rollers have corresponding widths of 75-200 mm resulting in track surfaces (the active area under the rolls) of about 500 to 7 500 cm².

The ring die press features a rotating perforated ring on which rollers (normally two or three) press on to the inner perimeter. Inner diameters of the rings vary from about 250 mm up to 1 000 mm with track surfaces from 500 to 6 000 cm².

Figure 15: Flat Die Type Pellet Press

Machine capacity and energy demand

The capacity of pellet presses is not restricted by the density of the raw material to the same degree as for piston presses. For material with very low density the flat die press performs better since the opening between rolls is larger for the same active surface area. What control the output of the machine is the power from the drive motor which means that there are large differences in machine capacity when materials with different frictional characteristics are densified.

Normally capacities given are valid for densification of animal feed which is much less energy consuming than wood waste, straw and similar raw materials used for fuel production. Often the capacity with the latter materials is a factor of 4 lower than for animal feed production. With this in mind, the output range for ring or flat die presses on the market is likely to be from about 200 kg/in up to 8 ton/in.

In pellet presses, the energy consumption is expressed as drive motor power per active surface area. Normally this surface load is in the 0.03 - 0.07 kW/cm² range.

Power consumption is by manufacturers said to fall within the range of 15 - 40 kWh/ton. We have no field data to verify these figures. One can assume that animal feed production results in power consumption at the lower end of the range while wood waste for example would demand 40 kWh/ton or more. Other waste materials, such as straw or husks, are likely to be even more energy consuming, in line with what is said about piston and screw briquetters. A theoretical comparison with piston presses is difficult since there are two factors, the smaller size of the individual holes and the lower pressing velocity, which counteract.

A common feature in pellet plants is to condition the raw material, often with steam, which decreases the energy consumption. The moisture content of the raw material corresponding to a need for conditioning is not known but is believed to be quite low, or about 5-7- %. Conditioning is also carried out to improve the digestibility of pellets used for fodder. Binders are added which increases the strength of the pellets (and thus chewing time) as well as making the raw material suitable as animal feed.

Capital and operational costs

The rather limited data for this type of press suggests capital costs per unit in the 20-40 US$/kg/h range. This would be for unit sizes from 6 down to 1 t/h when densifying wood waste. Wear of the dies is probably of the same order as for piston briquetters, i.e. a die lasts less than 1 000 hours. Manufacturers data indicate a maintenance cost of 5 US$/t valid for wood waste.

Use of pellet machines

The main application for pellet machines is to produce animal feed from various types of agricultural wastes. Only a very limited number of plants have been set up to produce fuel pellets. In such cases, the motive for choosing a pellet machine has been the large capacity needed and, to some extent, the better handling characteristics of pellets in automated transport systems. To our knowledge, all fuel pellets projects in industrial countries use woodwaste as the main feed.

Some limited experience has been gained with pellet machines for the production of fuel in Africa. It is doubtful that there would be many applications in developing countries given the large output of such a plant. However in cases where an output in excess of 1-2 ton/in is required and where a good market can be identified, pellet presses could be considered

No data is available on the combustion characteristics of pellets. However, given the differences between wood and such small pellets, an industrial market would seem most likely target. One plant in Kenya has been set up to provide fuel for a large wood-burning boiler.

Chapter 11.Auxiliary equipment

Only in a few cases will the briquetting press be the only equipment needed to set up a briquetting plant. Examples of such basic installations are the rice-husk screw briquetters in Thailand where raw material is fed by hand into the machine and collected by hand after pressing.

From this starting point, the complexity of briquetting plants increases up to the fully automated woodwaste briquetting plants found in Europe in which the raw material is fed by a tractor into a hopper from where it is crushed, screened, stored, dryed, stored again, fed into the presses and transported to the product storage in a fully automatic process, supervised by a couple of operators.

It would be far too complex to go into details about the features of each of the equipment types that can be found in densification plants. The following text is a brief description of a few common types and their applications.

Storage

Storage of raw material in developing country projects is likely to be in the form of open storage piles. This demands only a large enough open area adjacent to the process plant. For materials which will have to dried before briquetting there is normally no need to cover the pile in the rainy season. When processing dry material, some kind of coverage is necessary in order to enable operation in periods of heavy raining. For smaller operations, tarpaulins and sheds will offer some storage but the cost of adequate protection in buildings and silos, is likely to be prohibitive except for very large plants.

If a drier is included in the process, a storage bin must be installed for intermediate storage of dried material before briquetting. There are numerous different designs of storage bins with mechanical reclamation of the stored material. They are likely to be quite site specific, taking into account the material flow patterns and the physical characteristics of the stored material.

The briquetted end product will always have to be stored under cover as the briquettes will crumble and disintegrate if rained upon. Storage buildings are quite common but sheds and tarpaulins can offer enough cover, if the briquettes are hard-surfaced.

Handling

Handling normally makes up the largest group of equipment in large, automated plants. The understanding of the best application for each type of conveyor will ensure a cost effective and trouble free conveying system.

Belt conveyors are the most common for transporting the raw material between unit processes. Chain conveyors are normally used for severe operating conditions, or unregulated loading situations. Vibrating conveyors are normally used for feeding hammer mills and chippers, but can also be used for metering and screening the raw material

Bucket elevators are restricted to conveying material with limited particle sizes and are normally not used unless the short distance pre vents the use of inclining elevators to overcome large height differences.

Pneumatic conveyors can be utilised for conveying dry fine material such as bagasse and rice husks The cost of operating such systems is often prohibitive in developing countries, at least in fuel briquetting projects.

The briquetted product can be handled by several of the above unit processes. One simple solution, possible for the hardling of briquettes feaving a mechanical piston press, is to avoid breaking the briquettes and instead letting the machine push the material all the way to the product storage. Turns, even U-turns, are possible since the material is still warm and rather soft.

Comminution

The need for comminution is individual to each raw material Many residues can be briquetted without any preparation at all but for others can the necessary size reduction tee quite costly and sometimes prohibitive. For woody materials such as cotton stalks, a chipper can be used for the fist size reduction. It is necessary to prevent dirt and stones from entering the chipper together with the material or the knifes will get dull quickly

The most common size reduction equipment in briquetting plants are hammer mills. They crush the material into coarse or fine fractions, depending on the type of mill.

Classification

Unless the raw material is guarantied to be clean and contain no oversize particles, there must be a screening operation built into the process In this, oversize material is removed and normally sent back into the hammer mill.

Mechanical piston presses and pellet presses are especially sensitive to large particles entering the press. A screen and a metal remover is therefore recommended as minimum auxiliary in such plants.

The different types of screens: disc screens, shaker rolls, drum screens etc have different application depending on the type of material and the quality demand on the product.

Drying

Mechanical dewatering is normally possible only when the moisture content is very high and typically over 50%. Presses are normally very expensive to install and to operate and are unlikely to be used in developing country fuel briquetting projects.

Thermal drying is common and is achieved by bunting some of the product in a hot air furnace. The drying takes place either in a rotary drum or in a cyclone Dryers are normally the most expensive type of auxiliary equipment, both to install and to operate.

The following two cases are included to give an impression of the type of equipment that could be found in operating plants, and their related costs.

Table 7: Capital Costs; Case A

1 Chipper	37kW	31 800 US$
1 15m^3 Silo with dosing screw		29 000
1 60 mm Briquetting machine with 2 sets of wear parts		65 400
Packing		2 400
Total FOB price		128 700 US$
Capacity (18.5 kg/h/rm^2):	510kg/h	

Table 8: Capital Costs; Case B

1 Vibrating conveyor		
1 Metal detector		
1 Chipper		
1 Magnetic drum separator		
1 Drag link conveyor	Height: 10 m Inclin.: 60°	

1 Wet material silo	58 m^3 with 8 m feed screw	
1 Drum dryer In: 3 200 kg/in at 50% Out: 1 820kg/h at 12%		
Of this the dryer use:	320 kg/in	
Balance for briquetting:	1 500 kg/in	
1 Rechipper 10 m^3/h	75 kW	
1 Drag link conveyor	Height: 10 m Inclin.: 45°	
1 Dry material silo 58 m^3 with 8 m feed screw		
1 Intermediate feed bin	1.5 m^3	
2 Briquette presses	75 mm 60 kW	
Total price ex works		715 300 US$
Capacity (18.5kg/h/cm^2)	1 590 kg/in	

Part: 4.The economics of briquetting

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Chapter 18.Introduction to the economics of briquetting

The financial costs of briquetting are very dependent upon the nature of the project, in particular upon the raw materials used and the plant location. The object of this section is to provide an indication of what range of costs can be expected for both operating and capital costs and what is the resulting unit product cost. Whether or not briquetting is economic in any given location will depend critically upon how these unit costs relate to the price of the likely substitute fuels. Such prices vary so widely that it is impossible to generalise about the likely economic benefits of briquetting. It is hoped that the costs set out here will enable some preliminary decisions to be made as to the likely role of briquetting in particular circumstances.

The first two sections deal with capital and operating costs whilst the final section looks at the total unit costs of briquetting.

Chapter 19.Capital costs

The capital cost of a plant is not always easy to establish on a consistent basis.

In different circumstances there may be different conventions about what is included in capital cost: for example, estimates made by funding agencies tend to include a fairly generous amount for initial spare parts whilst commercially funded plants often include spares as part of operational costs.

Another major source of variation is whether the plant is a stand-alone operation or whether it is part of an existing plant. In the latter case, it is often possible to utilise existing buildings and to eliminate a significant element of capital cost. It is not unusual in plants with dedicated new buildings for these together with site civil works to equal the cost of new machinery.

Probably the biggest variation in plant capital costs, however, comes from the raw material to be used and the form in which it is collected. There are three reasons for this.

First, the nature of the residue may be such as to significantly lower the rated output of the briquetting machine. Normally machines are rated according to their output using wood-wastes and if less dense residues are used then the actual throughput may be less by as much as 50%. In one Indian plant visited, the machine used was capable of delivering 1.5 tonnes/hour fed with sawdust but only 1.0 tonnes/hour using rice-husk. As the cost of a briquetter seems to be almost linearly dependent upon rated output, the unit capital costs associated with a wood residue are likely to be lower than for most agro-residues.

Secondly, the form of the initial feed may require more or less rigorous treatment before it is fed to the briquetter as such. Some wastes, for example sawdust, often need to be dried to reduce their moisture to the 15% or so tolerated in most machines. The cost of a drier can easily equal or even exceed the cost of the briquetter itself. For example, the Brazilian manufacturer, Biomax, which makes both presses and driers, quotes a list price ex-factory of US$39 000 for a 1.1 tonnes/hour piston press, US$11 000 for associated conveyance and silos, and US$52 000 for a dryer plus heater of l tonnes/hour capacity. It is likely that in this case the cost of the briquetter is unusually low but the dryer is clearly a big additional cost.

Other ancillary equipment may include various types of chipper or shredder to reduce the size of the residue. This will be required for various forms of wood-waste other than sawdust and for certain types of agro-residue such as cotton stalks.

Thirdly, there is a very big difference between field-residues such as cotton-stalks or straw and factory-residues such as sawdust or coffee-husk if the cost of the equipment to collect the residue is included in the initial capital cost. This is not always the case; the straw-briquetting operations which have been set up particularly in Germany, often assume that existing tractors and trailers are available to collect the straw from the field.

If this is not the case then the capital costs of collection equipment are likely to be large. In a recent study of the costs of a wheat-straw briquetting plant in Ethiopia (World Bank 1986), it was estimated that 3 straw-balers, 5 trailers and 6 tractors would be needed to move 5 000 tonnes/annum of straw. The estimated cost was US$107 500 before transport to Ethiopia.

Finally, it should be noted that one important aspect of capital cost is what may be called the engineering and design standards of the plant.

This is difficult to define but easy enough to appreciate when making a site visit. Many, though by no means all, of the commercial plants visited were cramped, very dusty and sometimes dangerous with unguarded fly-wheels and rudimentary wiring. Such plants are often the ones which are squeezed into residue-producing plants to utilise existing buildings. Naturally, the capital costs of such plants are lower than plants which have firm floors, proper electrical fittings and are reasonably spacious.

This aspect is not necessarily related to the use made of labour rather than machinery to convey and store the residues and product. However, it is likely that in a plant where little or no use is made of mechanical handling, there will be a need to have spacious buildings to avoid problems of dust and dangerous overcrowding. In one of the Indian plants visited, this meant that the capital cost of the new buildings used was almost equal to the cost of the machinery. Thus savings made on ancillary handling equipment in favour of human labour may be partially illusory if reason able working conditions are to be maintained.

Nevertheless, it is probable that some of the development-agency funded projects are over-designed relative to privately funded projects with too great an emphasis placed upon mechanical handling, storage and bagging.

In order to put some numbers on these general comments, Table 12 shows the capital costs of six plants in various countries. Three of these are design studies (Plants A,B,E) which contain rather detailed cost breakdowns whilst three are of actual plants (C,D,F) for which rather less detailed breakdowns were available.

Table 12 shows the estimated capital cost per tonne of output for each plant assuming that it is required to pay back the initial capital sum with interest in a 10 year period. Three interest rates are shown: 7%, 10% and 15%. A number of other conventions could be used for the capital charge but they would make little difference to the results.

It can be seen that the plant with the lowest capital cost is Plant C based upon a unit at a wood-working factory in Brazil. This may be regarded as an extreme case; the raw material is dense and needs only chipping to provide an acceptable feed whilst the cost of a piston-briquetter in Brazil is much lower than anywhere else. The cost of buildings was minimal, amounting to little more than some covered space alongside the factory building. The products were removed daily to local customers so little on-site storage was required. The only equipment required in addition to the briquettes was a chipper and some simple pneumatic conveyance to a feed silo. The capital cost of 4.3 US$/tonne at 10% interest can be regarded as very much a minimum for any operation.

The four plants D,E,F,A are interesting as despite being for different materials at different sizes and in different countries, they show very much the same level of capital costs. It should be borne in mind that the figures in Table 12 have been put into a common currency and therefore may suffer from the usual problems of multi-currency comparisons.

Plant D is based upon an actual operation in Kenya where a small screw briquetter has been installed in an existing plant to feed an on-site wood boiler. The only equipment needed additional to the press was some modifications to an existing dryer. The amounts shown for spares and engineering and installation are notional as the expenses were not specifically itemised.

Plant E is a design study (World Bank 1987) for a new sawdust-based plant in Ghana using 6 Taiwanese screw-presses which would be supplied with a dryer. The additional equipment includes a lorry to collect raw materials and a fork-lift vehicle onsite.

Plant F is an actual Indian plant using rice-husk feed. The material requires no preparation and, as all handling is manual, there are no additional equipment costs. This low level of equipment costs is probably one reason why rice-husk briquetting has managed to retain some commercial viability in India despite its apparent disadvantages of high inherent ash content and raw material costs.

The plant required completely new buildings and these were provided, at this plant, on a generous scale. In other Indian plants, old buildings are used with a substantial cost-saving.

Plant A is a design study (World Bank 1986) for a plant using coffee-parchment sited at an existing plant in Addis Ababa which is planned to move in a short time. It is rather highly engineered with pneumatic conveyance throughout and a large intermediate storage silo. At the new site, the building costs are estimated at over US$57 000. Coffee parchment requires no preliminary treatment before feeding to the briquetter so the additional equipment costs shown are all for handling and storage.

The final plant, B. is a design study (World Bank 1986) for an operation based upon straw collected from the fields in Ethiopia. The very large additional costs required for this kind of unit are obvious with the capital charge at 10% rising to nearly US$32/tonne. The extra equipment needs arise not only from the field collection equipment but from the bale breaker, hammer-mill and associated conveyance equipment.

	(all in '000 US$)					
PLANT	**A**	**B**	**C**	**D**	**E**	**F**
Raw material	Coffee	Straw	Wood	Sawdust	Sawdust	Rice
Site preparation						
and buildings	57.3	92.2	5.0	0.0	58.2	110.0
Briquetting machine	149.0	206.4	39.0	9.7	58.0	112.5
Other equipment	45.6	405.6	44.1	4.5	56.0	0.0
Spares	0.0	19.4	74.0	1.0	1.0	0.0
Transport and delivery	16.3	54.1	4.5	0.0	12.3	0.0

Engineering and						
installation	29.2	149.2	5.0	1.0	52.0	2.2
Total	316.8	891.5	106.6	16.2	243.5	224.7
Annual output	5 000	5 000	4 000	300	3 500	4 000
	('000 tonnes)					
	Capital cost assuming a 10-year finance period					
	(US$ per tonne)					
@7%	9.0	27.9	3.8	7.7	9.9	8.0
@ 10%	10.3	31.9	4.3	8.8	11.3	9.1
@ 15%	12.6	39.1	5.3	10.8	13.9	11.2

These investment costs, although high, are not out of line with the capital costs reported for straw-briquetting in Europe. One plant (KTBL 1983) of 1 000 tonnes/annum throughput is quoted as costing US$150 000 in 1983, the equivalent of about US$900 000 when adjusted to the 500 tonnes/annum throughput of the proposed Ethiopian plant in 1986 prices. Another plant of only 375 tonnes/annum throughput is quoted as costing US$90 000 for equipment plus US$35 000 for storage equipment; the equivalent of about US$1.7 million when adjusted to 5 000 tonnes throughput. Although these German costs are difficult to compare directly on a consistent basis, they suggest that the briquetting of field residues is a very expensive operation which can only be justified in a context of high fuel prices. Straw briquetting is also justified in Europe because of environmental constraints on the burning of straw in open fields.

It seems reasonable to suggest on the basis of these figures that for centralised residues in most situations, a capital cost of 9-12 US$/tonne at an interest rate of 10% is reasonable. In circumstances where the provision of new buildings can be cut to the very minimum this might be reduced a little. Higher interest rates, and in most developing countries commercial loans would be somewhat higher, would add to this figure. A 15% rate would raise the level to about 11-14 US$/tonne.

Table 12: Comparisons of Capital Costs

Notes:

Plant A based upon World Bank coatings for a plant in Ethiopia at an existing coffee plant using 1 piston and 1 screw machine
Plant B based upon World Bank coatings for a plant in Ethiopia at at new site using 2 piston machines

Plant C based upon list-prices for a Brazilian plant at a wood-factory using 1 Brazilian piston machine
Plant D based upon a Kenyan unit at an existing factory using 1 screw machine and a modified existing dryer
Plant E based on World Bank coatings for a plant in Ghana using 6 Taiwanese screw machines with dryers included.
Plant F based upon an actual Indian plant using 1 Indian piston-press with no ancillary equipment located in new buildings.

Chapter 20.Operating costs of briquetting

Labour Costs

The labour costs of a briquetting plant are very dependent upon plant design; the scope of the operation, in particular whether there is any significant residue collection activity; the wage rates of the various categories of labour employed; and the extent to which the unit is integrated with a larger factory which can supply some labour needs on a part-time basis.

There is a tremendous variation possible between plants depending upon the balance of all these factors. It is, for example, quite possible to run a briquetter unattended for long periods, even overnight. This is common practice in Sweden where high wages place a considerable premium on labour reduction and where a wood-waste plant can only be profitable if left to operate automatically. Naturally, such operation increases the capital cost greatly and is not considered here as an appropriate mode in any developing country. However, without going to such extremes, it is possible to observe wide differences in the labour use in different operating plants.

The least direct labour use can be seen in plants which are in-house operations, that is plants contained in larger factories either to briquette their own waste or to produce briquettes for their own boilers.

In these situations, the labour costs of administration, loading and maintenance may be wholly or partly absorbed in the general activities of the factory. Thus in one Kenyan plant, only one unskilled worker was paid to work directly on briquetting; other labour costs were contained in costs for plant overheads or maintenance. Even so, the attributed labour cost was still quite high amounting to rather more than 5 US$/tonne of product.

The size of plant seems to play a significant part in determining labour costs with larger operations having unit labour costs up to 50% less than those of small plants. In India, a small plant based upon the carbonising technology appeared to have costs of about 8 US$/tonne without taking into account any salary to the owner/manager. At a single piston-press plant, labour costs were 3 US$/tonne including payments to 4 managerial staff (2 involved in selling the product), 15 unskilled workers employed seasonally and 4 skilled workers employed full-time.

An operational plant in the Sudan, working one-shift per day, employs 10 people including 2 operators and 1 trained engineer. The remainder are unskilled loaders, packers and guards. The smaller number of people employed as compared with the Indian plant may be related to the greater labour need of moving rice-husk as compared with groundnut shells. However, there is normally a wide variation found in the numbers of unskilled workers employed at such plants.

The total wages bill in the Sudanese plant was calculated as being S£13.4/tonne of product which was 12% of the total production cost. Although the Sudanese exchange rate has charged too fast in recent years for comparisons to be reliable, this is equivalent to 1.2-5.5 US$/tonne of product depending upon whether a current or the historic rate is used. No managerial wages were included in this Sudanese estimate nor anything for maintenance engineers. One might expect a somewhat higher wage cost if these were to be included.

As a general rule, one would expect the labour costs for a large plant (that is one producing in excess of 3-4 000 tonnes annually) to be in the range 3-5 US$/tonne provided the residues were centralised at the plant. If they had to be collected from the fields then labour costs would rise sharply. There are no data available on actual operational plants but a study made for a proposed Ethiopian plant (World Bank 1986), based on maize residues, proposed to employ over 250 people on collection and storage of the residues. The very low labour costs in Ethiopia kept the labour component down but, even so, total labour costs for the plant rose to 16.7 US$/tonne.

There is a strong trade-off to be made between labour and investment in mechanisation for any field-residue collection but it must be expected that, under any regime of mechanisation, labour costs would exceed 10 US$/tonne. In German plants based on straw, with high labour costs and correspondingly high levels of mechanisation, the labour cost can exceed 30 US$/tonne of product.

Despite the wide variations in labour cost, briquetting as such is not labour intensive relative to the unit capital costs and the cost of maintenance, power and other consumables. Labour costs seldom exceed 15% of the total and are usually much less. Even in the maize-residue plant, mentioned above, the estimated labour cost was only 15.4% of the total estimated factory costs including an annualised capital charge.

Maintenance

The maintenance of briquetting machines can be quite onerous particularly for screw presses and for piston presses operating on abrasive materials such as rice-husk. The actual assignation of maintenance costs varies according to the internal accounting practices of plants and to how maintenance is undertaken.

In some operations, in particular those using screw presses, an operative may be employed virtually fulltime on building up worn screws. Such work, though effectively continuous maintenance, may be registered as a labour cost. Even in such cases, however, the cost of welding rods may be high.

An analysis of the various plants visited as well as design studies and manufacturers' data suggests that the maintenance costs of piston presses are likely to be in the range 3-8 US$/tonne, whilst for screw machines, the equivalent range is 512 US$/tonne. This latter figure is wide partly because of the differences in treating maintenance costs but also because there are clearly variations between machines.

It is apparent that maintenance costs can be a significant element of briquette production costs and one that is often underestimated in planning plants. It is a factor which may place a continuing reliance on imported spare-parts possibly leading to delays in production if adequate allowance is not made in advance.

Power Costs

Most of the plants discussed here are powered by electricity from a mains supply. There is no reason why plants in remote areas should not use diesel generators (as does the Sudanese plant quoted above) or use direct drive from diesel or steam engines.

Analysis of available data suggests that for a practical plant, including some allowance for power-driven conveyance equipment, power consumption will fall in the range 50-80 kWh/tonne of product for piston presses and 100-120 kWh/tonne for screw presses. The unit power consumption of screw presses is quoted for small machines of about 150 kg/hour capacity and lower figures are quoted by the manufacturers of larger machines. These may be an accurate representation of the power savings available as machines get larger. However, there are relatively few of such large screw presses installed and good operational data are sparse.

Power prices vary considerably between countries; a range of 5-8 cents/kWh probably covers most places though in, for example, Brazil, power prices are much lower.

At such prices, the power costs of briquetting could vary between 2.5 US$/tonne and 6.4 US$/tonne for piston machines whilst small screw machines would have higher unit costs of up to about 9 US$/tonne.

The diesel-powered Sudanese plant consumed fuel which cost 19.2 S£/tonne of product or 7.6 US$/tonne at the exchange rate then prevailing. As diesel prices move closely with the exchange rate this is probably a reasonable dollar estimate of the real fuel cost. This suggests that diesel powered plants will have costs at or somewhat above those for electrically powered units.

It is common for the operators of plants located inside factories to have no clear idea of their power costs as electricity bills may be spread across other power-consuming units. The costs of power use do not seem to be regarded as a commercial problem warranting any attention and most plants put their unit power costs in the range of 2-5 US$/tonne. Some plants, particularly in Brazil, give even lower estimates but Brazilian electricity is very cheap.

Raw Materials

The price paid for residues, if any, is very much a site-specific issue and must be regarded as an add-on unit cost relevant to a particular project. However, even if the residue is nominally free, it is common for a transport cost to be incurred in bringing the residue to the briquetting plant. In the case of units sited at the residue production point this is avoided but for other situations the transport cost may be a significant part of operational costs.

As with maintenance, transport costs may be added into general labour costs if fulltime drivers are employed. A more common situation is to hire appropriate transport as a single briquetting plant needs to be rather large to warrant a dedicated lorry and driver.

In India, the cost of bringing rice-husk from local mills by bullock-cart was reported to be a little more than 1 US$/tonne whilst the cost of fetching wood-residues and sawdust in Brazil varied between 3 and 6 US$/tonne depending upon the distance moved. The latter figure corresponds to quite large transport distances and would be an unusually high level.

Other Costs

These include taxes, if appropriate, insurance, selling costs, consumables such as lubricating oil, packaging if needed and so on. It would be unusual if these dropped below 1 US$/tonne for any plant.

Chapter 21.Total costs of briquetting

Almost all the cost categories discussed above depend to a more or less significant degree either on accounting conventions (this is particularly relevant for the calculation of capital charges) or on site or country-specific factors. In addition no allowance has been made for the cost of raw materials over and above transport charges. The country studies make it clear that where briquetting has become commercially viable to a degree there is a tendency for residues to acquire a market price where previously they were free.

The cost ranges derived above for a large piston machine are:

	US$/tonne
Capital charge	9-12
Labour	3-5
Maintenance	3-8
Electricity	3-7
Raw materials	1-4
Other	at least 1

A simple addition of the least and greatest costs would suggest that a piston-machine briquetting plant would have total factory costs in the range 20-36 US$/tonne of product. It would however be misleading to adopt costs in the lower part of this range except under the most favourable circumstances; these might be the use of dry wood-waste drawn from the immediate locality in a country where labour costs and power prices are low and where fairly low-cost machinery is available.

A possible location meeting these criteria is Brazil; there a company planning to set up a number of large briquetting plants in the interior has suggested that total costs would be about 26 US$/tonne including some payment for wood-wastes. This must represent very much the bottom end of the cost range.

In other, less favourably situated countries, it is much more likely that total costs would be towards the upper part of the range. It should be emphasised that these do not include any allowance for residues being priced nor for any profit element.

It would be expected that the unit costs for screw presses would be somewhat higher than for piston machines. They do not appear to offer any significant advantages in investment costs and in some cost categories, notably maintenance and power, they are likely to be more expensive. They also appear to have higher unit labour costs though this is probably a factor relating to scale of production rather than any intrinsic feature of screw presses.

The higher intrinsic costs of the screw machines may however be offset by the fact that their small production levels, and indeed small physical size, means that they can be, literally, squeezed into low-cost situations. These would typically be a small wood-plant able to site a machine right by the waste pile in a building which needs little or no modification.

One Kenyan user who has put a small screw press into such a favourable situation (except that it utilises residue from a nearby sawmill) has assessed total factory costs at about 21 US$/tonne including depreciation and finance. This includes no allowance for raw material transport costs and may underestimate power and maintenance costs. If these are corrected then it is likely that true factory costs are more like 25 US$/tonne.

In general therefore, it would be wise to assume that total costs for briquette production are in excess of 30 US$/tonne and may be above 35 US$/tonne except in particularly favoured circumstances.

These numbers are in accordance with the situations in both Brazil and India, the two developing countries where briquetting has managed to establish some kind of commercial basis. In Brazil, it seems possible to survive by marketing briquettes somewhere above 30 US$/tonne whilst in India a marketed price in excess of 40 US$/tonne is required. In both cases, these prices produce bare commercial survival rather than large profits. In India, it is common to pay up to 15 US$/tonne for rice-husk; in Brazil, wood-wastes are usually cheaper if charged at all.

These broad cost levels refer only to plants based upon factory residues. The costs for any field residue plant will be much higher.

It is clear that in many countries, the price of fuelwood is well below these levels to an extent that effectively rules out briquettes as commercial propositions. This is often true even if it is assumed that industrial consumers are prepared to pay a premium for briquettes as they are of consistent and reliable quality.

There are exceptions to this. It is reported (World Bank 1986) that fuelwood prices in Addis Ababa reached 83 US$/tonne in 1985; even allowing for a retail markup this allows considerable scope for briquettes to undercut fuelwood. However, industrial fuelwood prices in, for example, Kenya do not exceed 20 US$/tonne, a level which briquettes cannot hope to reach. Similar low fuelwood prices in Thailand have effectively destroyed the local briquetting industry despite very low investment costs and good raw material availability.

It is probably true that in most countries, the current level of fuel prices is too low to justify briquetting. Nevertheless the examples of Brazil and India show that it is quite possible for fuel prices to rise to levels where briquetting is viable. Such a rise can, moreover, take place quite rapidly: the fuelwood price in Addis Ababa was reported to be only 9 US$/tonne in 1973.

The key policy issue in many countries with respect to briquetting must be the judgement as to the extent to which it is worth supporting briquetting activities, in spite of their immediate lack of profits, in expectation that fuel prices will rise in the future. There is no general answer possible to this. There are many countries where fuelwood prices seem set to remain relatively low for the foreseeable future. Indeed in some countries there is genuine optimism about the possibility of stabilising prices indefinitely by the development of fuelwood plantations.

However there are also countries where it seems likely that deforestation must cause a rise in prices in the not too distant future. In such circumstances briquetting of agro-residues can have a legitimate economic role without any need for subsidies.

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1987

Appendix III.List of manufacturers

Note:

The following list of manufacturers has been compiled for the service of workers in the field wanting contacts with companies able of delivering briquetting equipment. The list is based on replies to an inquiry mailed in mid 1987 to 173 addresses gathered from various sources. In 20 cases our letters were returned stamped R.T.S. and only in a couple of cases did we later manage to find the company's address. We have assumed that in most of the other cases the companies have seized to exist.

We received negative replies from 18 companies, most of them giving the reason that they had stopped commercial activities in the briquetting field. We have also excluded from the list another 7 companies that are either retailers or manufacturers of auxiliary equipment.

A reminder was mailed in January 1988 to those who had by then not replied at all.

The inquiry consisted of a rather detailed questionnaire asking for information about the equipment produced and the company's experience in especially developing countries. We managed to get satisfactory answers to these questions in only a handful of cases and with few exceptions these were answers delivered in conjunction with visits to companies. We visited in all 14 companies:

Amandus Kahl	West Germany
Hansa	West Germany
BHS (Spanex)	West Germany
Usine de Wecker	Luxembourg
BMD	Belgium
Destech	Denmark
Bogma	Sweden
ATS	Switzerland
Pawert/SPM	Switzerland
TISTR	Thailand
Sal Kampsaeng Motors	Thailand
S.P. Energy	Thailand
Biomax	Brazil
Ameteep	India

During the course of the study we came to realize that the information we asked for was generally regarded as proprietary business information which the companies were unwilling to give away. We have therefore avoided publishing that information that did come to the project from the cooperating companies in any identifiable way. However, we are thankful to these companies without whom a major part of the technical section in this report would have been much less detailed and accurate.

The 50 companies included in the list are companies that have responded to our inquiry indicating that they are active in the briquetting field. In a very limited number of cases we have also included companies that did not respond to our inquiry but where we have received reliable information that they are active under the addresses given here.

Since a majority of the replies from manufacturing companies only contained brochures and not complete answers to our questionnaires, we decided to limit the company information to addresses and their type of equipment and their capacity ranges.

Among the about 90 companies to which we had addresses but who did not respond at all there must be several who would qualify to be in our list. But as we feel that we have done what we could to contact these companies, we hereby decline any responsibility for the possible harm that could result from such omissions. Neither can SEBRA, SIDA or the publisher take responsibility for any harm or inconvenience that could result from mistakes we may have made when compiling the data from the companies.

Adelmann GmbH Environmental Engineering Division Postfach 11 50 D8782 Karlstadt West Germany
Phone: +49 93 53 7903 0 Telex: 689 724
Equipment type: Mech. piston Capacity range: 0.1-0.5 t/h

Amandus Kahl Nachf. PO Box 12 46 D-2057 Reinbek bei Hamburg West Germany
Phone: +49 40 7 27 71-0 Telex: 217 875 kahl d Telefax: +49 40 7 27 71 100
Equipment type: Disk die Capacity range: 0.1-10.0 t/h

Ameteep Machine Tools Pvt. Ltd 5th Floor, Surya Kiran, Kasturba Gandhi Marg New Delhi-110 001 India
Phone: +91 3313872
Telex: ND 2101
Equipment type: Mech. piston Capacity range: 0.1-3.0 t/h

ATS AG CH-8548 Ellikon an der Thur Switzerland
Phone: +41 54 55 22 31 Telex: 76519 ats ch Telefax: +41 54 55 22 35
Equipment type: Heated screw Capacity range: 0.7-2.2 t/h
Benson Granulier-Technik Carl-Zeiss-Strasse 8 D-2085 Quickborn West Germany
Phone: +49 4106 733 93 Telex:
Equipment type: Disk die Capacity range: -20 t/h

BEPEX GmbH
Postfach 9
D-7105 Leingarten
West Germany
Phone: +49 7131 4 00 82 Telex: 728738 Telefax: 49 7131 4 03 607
Equipment type: Roll Capacity range: N.A.

BHS Luft- und Umwelttechnik GmbH & Co. KG Spanex Otto-Brenner-Strasse
D-3418 Uslar 1 West Germany
Phone: +49 55 71304 0 Telex: 965710 Telefax: +49 55 71304 111
Equipment type: Mech. piston and hydr. piston Capacity range: .05-0.55 t/h
Biomass Development Europe SA Rue Van Hoorde, 34 B-1030 Bruxelles
Belgium
Phone: +32 2 242 02 95 Telex: 61 134 bulman b Telefax: +32 2 242 28 85
Equipment type: Con. screw Capacity range: 0.6-1.0 t/h

Biomax Indústria de Maquinas Ltda Rua Constelacao, 46, Villa Tereza, CEP
93000 Sao Leopoldo RS Brazil
Phone: +55 512 92 5742
Telex: 511219 xpsl br
Equipment type: Mech. piston Capacity range: 0.25-2.7 t/h

Bogma Maskin AB
Box 71
S-523 01 Ulricehamn
Sweden
Phone: +46 321 120 10 Telex: 36033 bogma s Telefax: +46 321 113 40
Equipment type: Mech. piston Capacity range: 0.75-1.0 t/h

Buhler-Miag GmbH
Postfach 3369
D-3300 Braunschweig
West Germany
Phone: +49 531 59 41
Telex: 952 700-0 bm d
Telefax: +49 531 594 2254
Equipment type: Ring-die
Capacity range: 3.0-15.0 t/h

California Pellet Mill Company
PO Box 6806
San Francisco, CA 94101

USA
Phone: + 1 415 431 3800
Equipment type: Ring-die
Capacity range: NA

CeCoCo
Chuo Boeki Goshi Kaisha
PO Box 8
Ibaraki,Osaka 567
Japan
Phone: +81 726 22 2441
Telex: J 65910 cecoco
Telefax: +81 726 27 9580
Equipment type: Heated screw
Capacity range: 0.12-0.17 t/h

C.F Nielsens Maskinfabrik A/S
9574 Baelum
Denmark
Phone: +45 8 33 74 00
Equipment type: Mech. piston
Capacity range: 0.4-0.9 t/h

Destech A/S
PO Box 127
DK-9400 Norresundby
Denmark
Phone: +45 8 17 52 00
Telex: 69615 destec dk
Telefax: +45 8 17 51 16
Equipment type: Mech. piston
Capacity range: 0.9-2.0 t/h

GHE Bavaria Maschinen GmbH
D-8701 Eibelstadt-Wünburg West Germany
Phone: +49 9303 351
Telex: 68789
Equipment type: Mech. piston Capacity range: 0.1-3.0 t/h
Guaranty Performance Co., Inc. PO Box 748 Independence, KS 67301 USA
Phone: +1 316 331 0020 Telex: 437014 guaranty inpe
Equipment type: N.A.
Capacity range: N.A.

Hansa Anlagenbau GmbH & Co KC Postfach
D-2200 Elmshorn West Germany
Phone: +49 4121 730 61
Telex: 218340 hansa d
Telefax: +49 4121 73625
Equipment type: Mech. piston Capacity range: 0.22-2.0 t/h

Holzmag Trading AG/Ltd Postfach
CH-4023 Baselsel-Freilager Switzerland
Phone: +41 61 50 09 66
Telex: 964 639 hong ch
Telefax: +41 61 50 34 54
Equipment type: Hydr. piston Capacity range: 100 kg/in

Kashtwabara Engineering Co Ltd
Yamato-Machi 1-23
Kashiwazaki-Shi Niigata-Ken Japan
Phone: +81 2572 4-1234
Equipment type: Screw&Roll
Capacity range: 0.3-0.4(Screw)&0.72-3.2(Roll) t/h

Krupp Industrietechnik GmbH

Werk Buckau Wolf
Postfach 100460
D-4048 Grevenbroich 1
West Germany
Phone: +49 218160 20
Telex: 8517280 ki d
Telefax: +49 2181 60 22 03
Equipment type: Mech. piston
Capacity range: 0.5-12.0 t/h

Kusters Venlo-Holland B.V.
Environment Technology
Postbus 315
5900 AH Venlo
The Netherlands
Phone: +31 077 540341
Telex: 58139
Equipment type: Screw
Capacity range: 3.0-4.0

Lupton Engineering Corp.
12 F-1, Chung Nan Bldg. E. 7 Tung-Feng St
Taipei
Taiwan
Phone: +886 2 702 9586
Telex: 20246 Daniel Tapei
Telefax: +886 2 702 7125
Equipment type: Heated screw
Capacity range: 0.12-0.36 t/h

Maatschappij Bronneberg Helmond B.V.
PO. Box 556
NL-5700 AN Helmond
The Netherlands
Phone: +31 4920 43445
Telex: 51070 broma nl
Equipment type: Hydr. piston
Capacity range: -4.5 m^3/h (infeed)

Maschinenfabrik Koppern GmbH&Co.KG
Postfach 800653
D-4320 Hattingen 1
West Germany
Phone: +49 2324 207 0
Telex: 8229965 koep d
Telefax: +49 2324 207 207
Equipment type: Roll Capacity range: N.A.

Maskinfabrik ACTA A/S
PO Box 271
DK-5100 Odense C
Denmark
Phone: +45 9 15 04 00
Telex: 9-29 18 15
Telefax: +45 9 15 35 57
Equipment type: Hydr. piston
Capacity range: 0.15-0.5 t/h

Miike Iron Works Company Ltd.
Shimoyasui, Shinichi-cho
Ashina-gun,, Hiroshima-pref.,729-31
Japan

Phone: +81 847 52 2537
Telex: -
Telefax: +81 847 52 33 16
Equipment type: Heated screw Ring-die Capacity range: 0.5 t/h (screw)3.5-5.5 t/h (Ringdie)

Nestro Lufttechnik GmbH
Schmachtenberger Strasse 7
D-8761 R llbach
West Germany
Phone: +49 9372 3044
Telex: 689207
Equipment type: Hydr. piston
Capacity range: 0.025-0.135 t/h

Orion Coal Company Limited
Shimada
2 Maruyama-Nakamachi,Maizuru
Kyoto-Fu
Japan
Phone: +81 773 62 2717
Telex: -
Telefax: +81 773 64 6397
Equipment type: Screw
Capacity range: 0.15-0.65 t/h

Pawert-SPM AG
Eidgenossenweg 14 a
CH-4052 Basel
Switzerland
Phone: +41 6142 00 80
Telex: 963225 pspm ch
Equipment type: Mech. piston
Capacity range: 0.15-4.6 t/h

PINI+KAY Maschinenbau GmbH
Singrienergasse 4 - 6
A-1120 Wien XII Austria
Phone: +43 222 83 64 24 Telex: 112 696
Equipment type: Heated screw Capacity range: 0.4-0.8 t/h
Promill BP 109 F-28104 Dreux Cedex France

Phone: +33 37 43 20 74 Telex: 760 732 f
Equipment type: Ring-die Capacity range: N A.

S.P Energy
53 M.6 Ladkrabang
Bangkok 105 20
Thailand
Phone: +66 328 8212 Telex:
Equipment type: Heated screw Capacity range: 0.08 t/h
Sahut, Conreur & Cie BP 27 F 59590 Raismes France
Phone: +33 27 46 90 44 Telex: 110 847 f Telefax: +33 27 29 97 65
Equipment type: Roll Capacity range:

Sai Kampang Saen Motors 356-359 Malaiman Rd. Kampangsacn, Nakornpathom 73140 Thailand
Phone: +66 34 351140 Telex:
Equipment type: Green fuel screw Capacity range: 0.5 t/h (wet basis)

Simon-Barron Ltd.
Bristol Road
Gloucester GL2 6BY
Great Britain
Phone: +44 452 306 511
Telex: 43231simbar g
Telefax: +44 452 300 164
Equipment type: Ring-die
Capacity range: 1.0-7.5 t/h

SPM Group, Inc.
1019 East Easter Way
Littleton, Colorado 80122
USA
Phone: +1 303 798 5949 Telex:
Equipment type: Mech. piston
Capacity range: 0.2-5.6 t/h

Sprout-Bauer Inc.
Process Equipment Division
Sherman Street
Muncy, PA 17756
USA
Phone: +1 717 546 1521

Telex: 841411
Equipment type: Ring-die Capacity range: N. A.

Surface S.A.
Division Sacmé Mirbo
B.P 14
Z.I. 86110 Mirebeau
France
Phone: +33 49 50 4171
Telex: 790459
Equipment type: Hydr. piston
Capacity range: 0.025-0.12 t/h

Thailand Institute of Scientific and Technological Research
Energy Technology Department
196 Phanonyothin Road, Bang Khen
Bangkok 109 00
Thailand
Phone: +66 1 579 6517
Equipment type: Heated screw
Capacity range: 0.3-0.4 t/h

Thetford International Mundford Road Thetford, Norfolk IP24 lHP Great Britain
Phone: +44 842 62861 Telex: 817432 Telefax: +44 842 62926
Equipment type: Hydr. piston Capacity range: 0.12 t/h

Ulrich Walter Maschinenbau GmbH Postfach 10 02 49 D-4020 Mettmann West Germany
Phone: +49 2104 14 03 0 Telex: 8 581230 Telefax: +49 2104 12 05 4
Equipment type: Ring-die Capacity range: N.A.

Usine de Wecker S.a.r.l. L-6703 WECKER Luxembourg
Phone: +352 7 10 02 Telex: 2237 WECKR LU Telefax: 352 7 1367
Equipment type: Heated screw Capacity range: 0.2-0.45 t/h

V.S. Machine Factory 90/20 Ladprao Soi 1 Road Bangkok 10900 Thailand
Phone: +66 1 513 3643 Telex:
Equipment type: Heated screw Capacity range:
Valmac S.P.A. Gruppo A Costa 1-36 040 Valdastico (VI) Italy
Phone: +39 445 745 388 Telex: 481328 valmac i
Equipment type: Mech. piston Capacity range: 0.38-2.2 t/h

van Aarsen Machinefabriek BV
P.O. Box 5010
NL-6097 ZG Panheel
The Netherlands
Phone: +31 4747 9444
Telex: 36839 aarse nl
Equipment type: Ring die
Capacity range: 2.5-30 t/h

Ventec Ltd.
Bluebridge Industrial Estate
Halstead, Essex C09 2EX
Great Britain
Phone: +44 787 473794
Telex: 987821
Telefax: +44 787 474 270
Equipment type: Hydr. piston
Capacity range: 0.5 t/h

Visser Internat. Trade & Eng. B.V.
P.O. Box 5103
3295 ZG 's-Gravendeel
The Netherlands
Phone: +31 1853 2644
Telex: 29475
Telefax: +31 1853 4649
Equipment type: Hydr. piston
Capacity range: 0.4-1.0 t/h

WACON Industrial Corp.
PO. Box 9-58
Taipei
Taiwan
Phone: +886 2 707 6664
Telex: 28995 wacoin
Telefax: +886 2 709 2404
Equipment type: Heated screw
Capacity range: 0.11 t/h

Warren and Baerg Mfg., Inc.
39950 Road 108
Dinuba, CA 93618

USA
Phone: + 1 209 591 6790
Telex: -
Telefax: + 1 209 591 5728
Equipment type: Ring-die
Capacity range: 5.0-10.0 t/h