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An Overview of Possible Uses of Sawdust

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AN OVERVIEW OF POSSIBLE USES OF
SAWDUST

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SAWDUST

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TOOL

TOOL is a Dutch foundation linking eleven (non-profit) groups which together involve about 400 volunteers based in universities, technical colleges and consulting engineering firms.

CICAT

The Centre for International Co-operation and Appropriate Technology is a multi-disciplinary centre of the Delft University of Technology.

CICA/CMP

The Office for Development Co-operation is established by the Eindhoven University of Technology as supporting office for the International Co-operation Group.

Numerous people in developing countries find themselves in a very difficult economic and social predicament. Appropriate Technology can, in many cases, solve their problems. By placing at their disposal knowledge and technology, appropriate to the local circumstances, the above mentioned organisations wish to help improve the position of the less fortunate in society.

abstract Kenya/fuel uses: direct combustion; briquetting; carboni-
(keywords) zation; gasification/ agricultural uses: litter for
poultry and cattle; fertilizer; animal feed/ building
material uses: insulation; reinforcement; particle board
making/ chemical uses: wood pretreatment; pulp- and paper-
making/ miscellaneous uses

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SUMMARY AND CONCLUSIONS

Forests in developing countries are an important natural resource: they provide wood for fuel and for building material. A by-product of woodprocessing is sawdust. In Kenya for instance, in the non-densily populated areas, where the majority of the sawmills is situated, the sawdust is considered fairly useless and is therefore dumped in the direct surroundings of the mills and burned. Huge piles of smouldering sawdust are the result. It can be assumed that a similar situation exists in developing countries with comparable forestry resources.

The department of Social Housing, Physical Planning and the Environment of the Government of the Netherlands invited the TOOL Foundation to make a short survey of the possible uses of sawdust in developing countries, with special reference to Kenya. TOOL made this survey in cooperation with the Centre for International Cooperation and Appropriate Technology (CICAT) of the Delft University of Technology and the Committee for International Co-operation Activities (CICA) of the Eindhoven University of Technology.

In the survey the following possibilities to use sawdust are described:

- Fuel from sawdust (Chapter 1)
- Agricultural uses of sawdust (Chapter 2)
- Sawdust in building materials (Chapter 3)
- Sawdust in chemical industries (Chapter 4)
- Miscellaneous uses of sawdust (Chapter 5)

The chapters 1, 2 and 3 are written by ir. G.J. Arends of the Delft University of Technology, Chapter 4 by dr. S.S. Donker-sloot-Shouq of the Eindhoven University of Technology and Chapter 5 by the TOOL staff.

The survey is probably not exhaustive: from the Dutch viewpoint it seems impossible to get a complete list of all the uses of sawdust that have been researched, developed and discovered in the world. However, the survey gives a fair idea of what things one can do with sawdust.

The processes and techniques used in the treatment of sawdust show a wide variety: from use in its natural form to subjecting it to sophisticated processes; from labourintensive to capital-intensive techniques; from the use of sawdust alone to its use in combination with all kinds of other materials; from low energy input to high energy input; from a small supply of sawdust to a large supply; etc.

This variation makes it difficult to classify all the processes described in the survey. The more so because the available material does not describe all possible aspects to a comparable extent. Sometimes the mechanical aspects of a process prevail, sometimes the chemical, sometimes the economical. This imbalance of information (for which nobody can be blamed, of course) is reflected in the survey.

The first and foremost conclusion that can be drawn from the survey seems fairly obvious: sawdust is useful.

Sawdust is a very useful byproduct of woodprocessing and it would be a pity if it would remain what it is often considered to be: waste. There are simple sawdust-treatment techniques that can be used straightaway in developing countries. To avoid possible misunderstandings: many of these techniques are already in use there.

On the other hand one has to realise that the choice of appropriate techniques in general is highly dependent upon local conditions. Only a detailed insight in local circumstances makes relevant decisions on what to do with the sawdust possible.

This detailed knowledge was not -yet- available for Kenya. Therefore the special reference to Kenya unfortunately will not be so special as it should be.

The second general conclusion is: transportation costs will be the most decisive factor in the choice of sawdust-processing techniques. Sawdust has a low specific gravity, is bulky and is therefore expensive to transport. Sawdust should therefore be processed in the immediate surroundings of its production-source: most of the products that can be made with or of sawdust are easier to transport than sawdust itself.

The information in the survey has to be read from the point of view of appropriate and intermediate technology. TOOL sees such a technology as small scale, based on local resources, labour-intensive, easy to manage and, within this context, economically viable.
Just as it was impossible to make a proper classification of the sawdust-treatment technologies on the basis of the available material, it proved equally impossible to make statements on which process or technique should be considered appropriate or intermediate and which should not.

Modern high technology asks for an extensive infrastructure in terms of transport, marketing- and management-facilities. This is not the infrastructure found in developing countries. Also the oversupply of labour and the undersupply of capital are not exactly prerequisites of high technology. This does not automatically mean, however, that for example a high-tech mobile pyrolisis system to produce charcoal should be excluded beforehand. It only means that detailed studies of the local conditions have to be made before appropriate decisions can be made on what to do with these smouldering stacks of sawdust.

1. FUEL FROM SAWDUST

Wood is the first and oldest means for firing. Since sawdust is finely subdivided wood-fibre, it can be used for fuel, like wood. The most obvious way to do so is to burn it in its natural form: direct combustion.

Some direct combustion drum-stoves have been developed for domestic use. Sawdust can be directly combusted for industrial purposes in

- fixed-bed combustors
- spreader-stoker combustors
- suspension combustors and
- fluidized-bed combustors.

Sawdust is bulky and consequently expensive to store and to transport. Besides, the heating value is relatively low.

Briquetting is an obvious way to decrease the bulk and to increase the heating value. Other methods to increase the heating value of sawdust are carbonization and gasification.

The borderline between direct combustion, carbonization and gasification is difficult to draw. The Engineering Experiment Station of the Georgia Institute of Technology has developed a system which produces charcoal, oil and gen-gas at the same time.

Briquetting can be done with and without a binder.

Briquets can be pressed without a binder by manual, animal and mechanical power. There is quite a variety of automotive compaction machines on the market. Sawdust-briquets can also be pressed with organic, inorganic and fiber-binders. Charcoal briquets can be made either by pressing prepared charcoal or by carbonization of wood briquets.

Carbonization is the transformation of wood into charcoal. There are two systems of sawdust-carbonization: fluidized-bed carbonization and the mobile pyrolisis system.

Sawdust can also be converted, by gasification, in the so-called gen-gas. Gen-gas can be used for heating and as fuel for an internal combustion engine.

Gasification systems are:
- the fixed-bed gasifier
- the co-current bed gasifier
- the fluidized-bed system
- the Imbert stationary and mobile gasifiers
- the Lambiotte gasifier
- the Gunnerman gasifier
- an urban waste-woodwaste blend gasifier.

The state of the art of the different uses of sawdust and their technologies varies considerably.

Direct combustion and briquetting is already common practice in many places in the Third World. The techniques used comply to some extent with the criteria for appropriate technology. There is an ample room for improvement and further research, however, for instance the direct-combustion drumstoves can be improved considerably. Direct combustion for industrial purposes could be considered when there is a large and steady supply of sawdust. Its most obvious application is of course supplying the energy for the sawmill itself.

It seems appropriate to stimulate the use of briquetting techniques in order to facilitate handling of the fuel and decrease transportation costs. When binders are being used, possible negative effects on the environment have to be taken into account.

The capital and infrastructural investments of the carbonization and gasification techniques are, on the whole, considerable.

More research and fieldtesting is necessary before decisions on the appropriateness of these techniques for developing countries can be taken.

2. AGRICULTURAL USES OF SAWDUST

Sawdust is an organic material, so the search for profitable applications in agriculture is obvious.

Agricultural uses of sawdust are: litter and bedding, fertilizer, soil-conditioner and feed.

The use of sawdust as litter and bedding is literally widespread. The deeplitter poultry system is an economic method of converting sawdust and shavings into a usable compost in temperate zones. In Zambia such a system, appropriate for a tropical climate, was developed. In Malawi a method has been developed to obtain good fertilizer by using sawdust as litter in a cattle corral.

There is an increasing use of sawdust as mulch, which retards erosion, hinders weed growing, reduces water evaporation, insulates the soil and keeps plants and fruits clean.

Sawdust can be used as fertilizer, although chemical substances have to be added and the composting time is 6 to 8 months. Quite some research on the conversion of sawdust into fertilizer and soilconditioner is being done in countries in the temperate as well as in the tropical climate zones. Wood is a potential source of energy for ruminants. Of course, it has to be made digestible first.

Generally many of the agricultural uses of sawdust can be considered appropriate for developing countries. This applies especially for the use of sawdust as litter and fertilizer, as the required technologies are fairly cheap and easy to apply.

The production of cattle-feed from sawdust requires a much greater capital investment. Besides, research in this field has to be geared more to the situation in tropical areas.

3. SAWDUST IN BUILDING MATERIALS

Wood is the most prevalent building material. Since sawdust is a byproduct of woodprocessing, a lot of research has already been done and is still being done on the use of sawdust as building material. In its natural form sawdust can be used for insulation (thermic isolation as well as noise prevention), for reinforcement and for climate control on fresh concrete surfaces.

Sawdust is also being applied in stony materials. Mixed with clay it is used in the production of bricks to decrease the weight and to increase their isolating capacity. Sawdust can be used as filler in mortar, which than becomes lighter and cheaper.

It is also possible to use sawdust in wood concrete and wood granite. Until recently the quantity of sawdust that could be used for the production of boardplates was limited to ± 20%. Techniques have been developed by which plates can be made nearly completely out of sawdust.

In India experiments are carried out with lowcost particle boards of sawdust and fibrous agricultural waste.

In order to use sawdust in fiberboards it has to be pulped first. Various methods for pulping sawdust have been described in chapter 4. In the USA fiberboards are made almost exclusively on a sawdust basis, while in Sweden medium hardboard is made of up to 100% of sawdust with a little glue added. Sawdust is a good raw material for the production of medium-density fiberboards, which can be used both in interior and exterior construction.

Many sawdust applications in the building industry are known and have proved their viability.

Some of these techniques are cheap and easy to handle, especially when the sawdust is used in its natural form or in stony materials.

However, the unavoidable transportation costs reduce the attractiveness of these uses.

Application of sawdust in board products is a complicated and capital-intensive process. The choice for boardproduction seems only appropriate when large amounts of sawdust are regularly available and when the market for the boardproducts is close by.

4. SAWDUST IN CHEMICAL INDUSTRIES

It is possible to convert wood or sawdust into a number of useful products by chemical processes. Various methods to achieve this purpose have been described in this chapter. These methods will now be briefly evaluated.

Wood pretreatment and fractionation

In this process sawdust is separated into its primary constituents. These can be converted into desired products, using different conversion processes.

This highly promising method has been, and still is the subject of extensive research. However, the process of autohydrolysis, i.e. pretreatment with steam, has been demonstrated to produce high-energy ruminant feed from a wide range of crop-residues and hardwoods. At present continuous autohydrolysis systems are producing cattle feed at two locations. It is high technology (high-pressure steaming) but not too complicated. It could be adopted in some developing countries.

Wood hydrolysis

Sawdust or wood on acid hydrolysis yields a mixture of sugars, which can be used directly as a feed (molasses) for ruminants, or can be converted into other products.
Due to the recent interest in the utilization of waste wood, research on wood hydrolysis is being carried out in

a number of countries. At the moment, however, the products are not sufficiently valuable to pay the cost of collecting, handling and processing of raw material. At the same time interesting developments are being reported, for instance production of yeast as an animal feed.

Pulping of sawdust and wood

Sawdust also seems to be a potential raw material for producing pulp. The important processes for pulping wood and sawdust are given in section 4.4 and constraints and opportunities for mechanical pulping are discussed there. In principle sawdust can be used to produce pulp of acceptable quality. Sawdust pulp can easily be blended with a longer-fibre pulp in various ratios, depending upon the desired end-products, or used as a filler to produce various paper and paper-board grades. Bleached sawdust pulp (10-20%) can be blended to produce a paper of good quality.

The choice of pulping method depends on the local tree species, the price and the availability of base chemicals for chemical pulping and of energy for mechanical pulping. Sawdust is not an easy material for pulpmaking and successful utilization has only developed at places where experience and expertise in this technology go together with good research facilities. The latter are especially important as the applied method has to be optimized with respect to local conditions and local wood varieties. In order to reduce transport problems (as often encountered in developing countries) it seems desirable to set up small integrated sawmill/pulpmill/papermill combinations.

Environmental considerations demand a mainly mechanical pulping method.

Wood extractives

Small amounts of valuable substances can be extracted from wood or sawdust from special trees. Extraction methods are simple and well known. These methods are given in section 4.3. However, they can be applied to only a few wood species.

These methods are already practised in some developing countries. In Kenya, for example, tannins, sandal oils and cedar oils are extracted from special trees.

The overall conclusion is that at present no chemical process is directly applicable in developing countries. However, from the point of view of the precarious food situation existing in large parts of Africa at the moment, the potential of woodwaste and sawdust as a nutrient for ruminants must not be ignored.

It is possible to convert sawdust into animal feed! Some methods have been described in chapters 2 and 4. These methods are simple and easy to handle. However, they could be improved further. A suitable and simple method of pre-treatment should be evaluated for use in developing countries.

In some countries like Pakistan intensive research is already going on* to convert agricultural waste into ruminant feed. Also feeding tests on animals are performed.

In such developing countries, where expertise and facilities are available a collaborative R and D programme on the utilization of sawdust as a raw material could be carried out.

* From author's visit to Pakistan.

5. MISCELLANEOUS USES OF SAWDUST

Sawdust compacted under high pressure with glue supplies a moulding material for the production of interior building elements and household appliances. It can also be used in the production of linoleum and wallpaper. These uses, however, require complicated production processes and considerable capital investment.

More appropriate, i.e. for situations in which no high capital investments are possible, are the following uses.

Sawdust is used in the leather industry to facilitate the staking and tacking of skins and in the fur industry to get the pelts into a pliable condition and to clean them.

Selected sawdust is frequently used for curing meat and fish.

Sawdust is a good packing medium.

It can also be used for fire extinction, filtering, stuffing, cleaning, fire-lighters and bottle-stoppers.

In France it is sometimes even used as a substitute for bran in bread-making.

1

FUEL FROM SAWDUST

ir g.j. arends

1. FUEL FROM SAWDUST

INTRODUCTION

Wood is the first and oldest means for firing. Since sawdust is just finely subdivided wood-fibre, it can be used for fuel too. Table 1.1 gives a typical analysis of hogged fuels (6)*. There are some problems however. Sawdust forms a layer which

* Numbers mentioned between brackets refer to the references listed in the bibliography.

Table 1.1

	Western Hemlock	Douglas Fir	Fine Sawdust
Moisture as received %	57.9	35.9	-
Moisture air dried %	7.3	6.5	6.3
Proximate Analysis, dry			
fuel Volatile matter %	74.2	82.0	79.4
Fixed carbon %	23.6	17.2	20.1
Ash %	2.2	0.8	0.5
Ultimate Analysis, dry			
fuel Hydrogen %	5.8	6.3	6.3
Carbon %	50.4	52.3	51.8
Nitrogen %	0.1	0.1	0.1
Oxygen %	41.4	40.5	41.3
Sulfur %	0.1	0.0	0.0
Ash %	2.2	0.8	0.5
Heating value, dry (MJ/kg)	20.1	21.1	21.2

is very impervious to air when it is burned in a normal stove or hearth, and because of its fineness it falls through the fire-grate.
Over the years many ways of economical ways to use sawdust as a fuel were developed.

Besides the possibility of the direct combustion of sawdust, several methods to convert sawdust in one or more eminent fuels were developed.
A more physical method is to compress sawdust to briquets, with or without a binder. Chemical methods are carbonization, gasification and distillation. Table 1.2 shows the heating value of several wood-based fuels.

Table 1.2   Gross calorific value of various wood based fuels (13)

Fuel			Quantity	Gross energy value (MJ)
Wood	green	(100 % MC)	1 tonne	10 000
	air dry	(10 % MC)	"	18 200
	oven dry		"	20 000
Charcoal			"	32 000
Pyrolytic oil			"	23 000
Char/oil	(10 % char)		"	42 500
	(20 % char)		"	41 600
Reconstituted wood	(10 % MC)			
- extruded/compacted briquettes				
and pellets			"	18 000
- 1:1 petroleum wax/wood logs			"	34 900
Methanol			"	23 900
Ethanol			"	30 700
Wood gas	air blast		1 m^3	3.7 - 5.6
	oxygen blast		"	11.0 - 14.0

MC = Moisture Content, oven-dry basis.   Fuel oil cal. value = 43 400 kJ/kg

In this chapter we will describe successively direct combustion (1.1), briquets from sawdust (1.2), carbonization (1.3) and gasification (1.4).

The borderline between direct combustion and gasification is difficult to draw. In this study gasification with direct combustion in the same installation, is considered as direct combustion and described in section 1.1. Systems which offer more than one wood-based fuel are described according to the most important product.

Figure 1.1 shows a plant in which sawdust and bark are converted into charcoal, oil and gen-gas, by a fixed-bed system.

This system was developed at the Engineering Experiment Station of the Georgia Institute of Technology (Atlanta, USA) and constructed by Tech Air Corporation. The system operates at about 600°C. The char produced has a heating value of 25.6 - 31.4 MJ/kg, the oil 23.3 to 30.3 MJ/kg and the gen-gas 7.5 MJ/m^3. A part of the gen-gas is used to dry the feed waste to 4% moisture content.
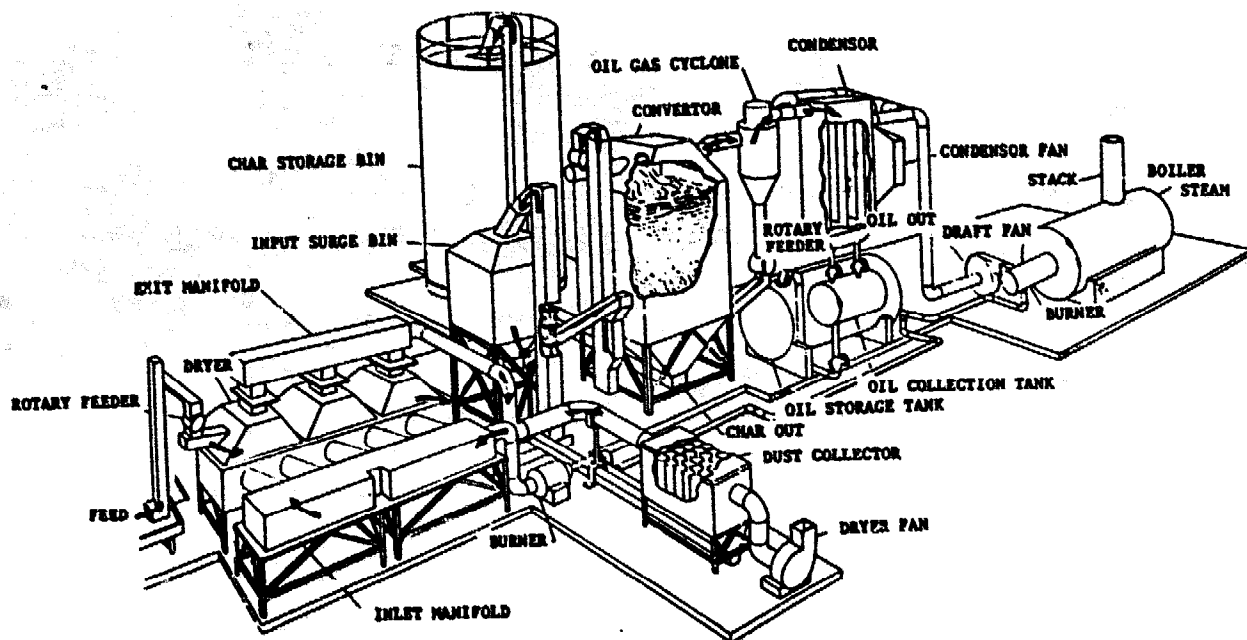
Figure 1.1   The Tech-Air system (27)

Analysis of the wood-based oil produced in the Tech-Air facility (figure 1.1) shows, that the heat values of the heavier wood oils range from about 60% to 70% of the heating values of fuel oils. The wood based oils contain no sulphur, so they do not create any sulphur emission problem when burned (20).

Oil is mostly a by-product of gasification or carbonization. However, liquid fuels can be stored and transported easily, so they are the most versatile forms of energy.

At the Pittsburgh Energy Research Center (Penn., USA) a system is developed to convert wood-waste into a bitumen or heavy oil by processing it with water, sodium carbonate and carbon monoxide at temperatures of 250 to 400°C and pressures of 10.5 to 24.6 MPa.

1.1 DIRECT COMBUSTION OF SAWDUST

One method to burn sawdust in its natural form is to adapt an incinerator.

Generally sawdust has a low heating value, because of its usually high moisture content (varying from 30% to 60% of its weight)(18). 1 Kg of dry sawdust has a heating value of almost 20 MegaJoule. This is comparable with about 0.7 kg of coal, about half a litre of fuel oil, or 0.5 cubic metres of natural gas (6,8). The heat value of hogged wood with a moisture content of 50% of weight is half the heating value of wood waste with a moisture content of 10% (6). Combustion of sawdust at the sawmill is the simplest digestion method.
Table 1.3 gives a comparison of the cost per heat value of several fuels with respect to the cost of sawdust (ex mill), before and after the energy crisis.

Table 1.3 Approximate cost of energy from various fuels in
relation to the cost of sawdust

Fuel	1971 [1]	1981 [2]
Sawdust ex mill	1	1
Do plus 100 km cartage		2.5
Chips ex mill		1.7
Bark ex mill	0.7	
Coal		2.3
Fuel oil	4.1	12.3
LPG		13.2
Natural gas	3.3	5.8
Electricity		23.2

[1] U.S.A. (7), [2] Australia (13)

When discussing the direct combustion of sawdust a distinction has to be made between the use of sawdust as home fuel and industrial combustion.

1.1.1 SAWDUST AS HOME FUEL

The following figure shows a very simple stove:
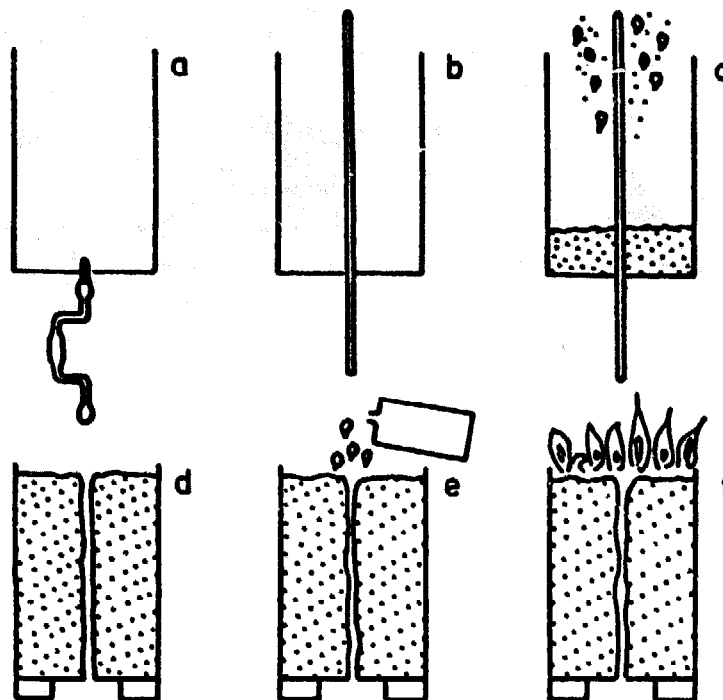
Figure 1.2 A simple stove (17)

It can be made of a 5 gallon square can in the following way (25):

a. Drill a hole in the bottom;

b. Put a broomstick in the hole;

c. Fill up the can with sawdust. The sawdust has to be moistened and rammed down after each inch;

d. Remove the broomstick and place the filled can on some bricks;

e. Sprinkle some diesel oil or kerosene on the top of the hole;

f. Kindle the lightly oiled area.

The sawdust will burn for 6 to 7 hours, while the burning rate
can be controlled by moving the bricks at the bottom of the
can, to vary the airflow through the hole.

Figure 1.3 shows an improved version, which is safer and can
be used inside a house. Instead of one hole, the stove has
four holes. The burning takes place wholy inside the stove,
while the flue gases are removed through the exhaustpipe. The
stove is removable to enable filling outside the house.
Filling and igniting is done similarly to the previous stove.
2 Kg of sawdust will give 4 to 5 hours of good cooking fire
(26).

No		
No	1	Five gallon can
No	2	Grill
No	3	Pot
No	4	Support (rod ¼ dia)
No	5	Support (rod ¼ dia)
No	6	Support (2) (rod ½ dia)
No	7	Reducer fitting 10x18 to 8x16 cm
No	8	Reducer fitting 10x18 to 7x15 cm
No	9	Duct of 10x18x45 cm
No	10	Duct of 10x18x70 cm
No	11	Duct of 10x18x57 cm
No	12	Suction exhaust hood of 10x30 dia
No	13	Duct of 10x18x107 cm
No	14	Cap

Figure 1.3 A simple home cooking stove (17,26)

On this basis several stoves were developed, such as the
double drum stove (figure 1.4) with a removable inner drum,
and made from heavy sheet steel. This one is more suitable
for heating a room (34).
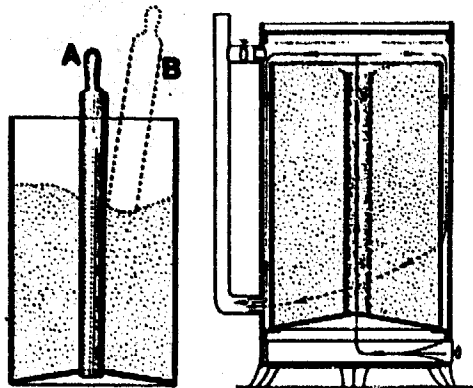
Figure 1.4 The double drum sawdust stove with innerdrum A and
           rampole B (34)

1.1.2 INDUSTRIAL COMBUSTION

Formerly, in order to cut down on fuel-expenses, most sawmills
heated their dry-kilns by burning wood wastes.
Many sawmills and other woodworking plants used their wood
waste to feed industrial and central heating boilers. Later
on, sawdust was used as fuel too. This trend was caused by
the increasing demand for solid wood waste by other indus-
tries, the possibility of automatic feeding of the incine-
rators, and the high cost of disposing of this waste (13).
There are four general types of industrial wood-fired furnaces
(6,8,13):
    a) The fixed-bed combustors;
    b) The spreader-stoker combustors;
    c) The suspension combustors;
    d) The fluidized-bed combustors.

a) THE FIXED-BED COMBUSTORS

In the fixed or packed-bed system, the fuel is dropped through a hole so that a pile is formed, which is supported by a grate through which air is passed (figure 1.5). Before the material drops through the grate as ash, the wood waste goes through the successive drying, carbonization and gasification zones. When there is insufficient air for complete combustion, extra air is added above the pile (or into the second chamber) to enable the combustible gases and vapours to burn.

Variations can be found in the way the pile is fed and whether or not there is a second compartment to burn the gases in.

The oldest and most simple, though common system is the Dutch Oven, which consists of two chambers (figure 1.5). In the first one the wood waste (sawdust and other hogged wood waste) is dried and gasified. In the second one, the combustion is completed under a boiler (6,13,8). Dutch Ovens can meet most anti-pollution requirements.
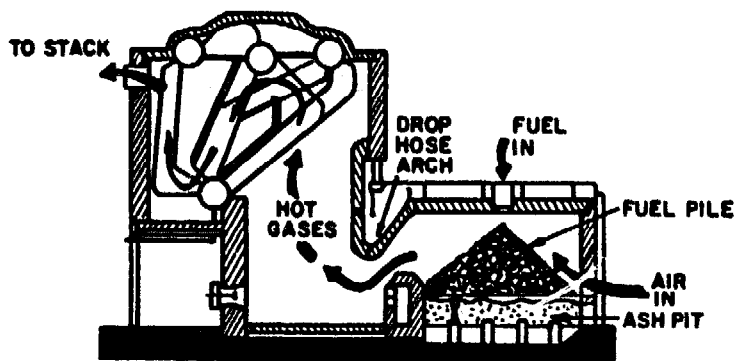
Figure 1.5 A Dutch Oven with steam boiler (6)

More recent combustors are the sliding grate combustor, the underfeed system combustor and the endless screw combustor (figure 1.6) (19).
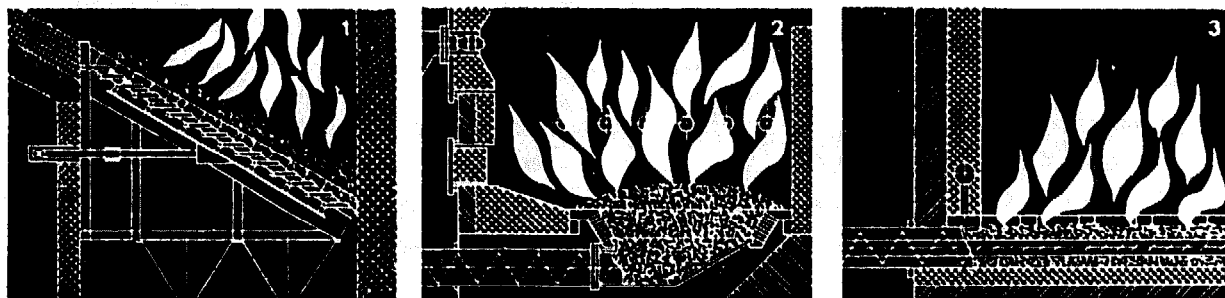
1. Sliding grate   2. Underfeed system   3. Endless screw

Figure 1.6 Some fixed-bed systems (19)

The sliding grate combustor has a mechanically movable iron grate, with a drying zone, a combustion zone and a post combustion zone. It even can be fed with sandy and humid wood waste. The ash is removed automatically.

The underfeed system combustor is fed by a screw conveyor so that it looks like a mole hill. Primary combustion air is blown through the fuel, while secondary air is added at the top of the hill for combustion. The combustion efficiency is optimal if the total added air is slightly above the requirements. The maximum admissible humidity is 40%. An example of this system is the Kara-M.I.N. combustor, constructed by Kara, Almelo, the Netherlands. Kara also manufactures smaller, hand-filled sawdust stoves (19).

The endless screw combustor is fed by one or more screws. It can be used for fuels with a high ash content, and a maximum humidity of 40%. Primary combustion air is blown through the blades of the screw(s) and secondary air is added just above the glowing solids.

b) THE SPREADER-STOKER COMBUSTORS

Spreader-stoker or stoker feeder furnaces are fed by a pneumatic or mechanical spreader system. It is more or less an intermediate form between the fixed-bed and the

suspension combustors. A portion of the sawdust (or other fine wood waste) is burned in suspension, while the rest is spread in a thin bed over the grates where the combustion is completed (6,8,13). They are very popular but the pneumatically fed combustors especially produce a large quantity of flue gases, which reduces the profit (19). To meet rigid air pollution standards, an expensive, high-efficiency collection equipment would be required (8).

A typical arrangement of a complete direct combustion system with a spreader stoker is shown in figure 1.7A. A detail is given in figure 1.7B.

A   B
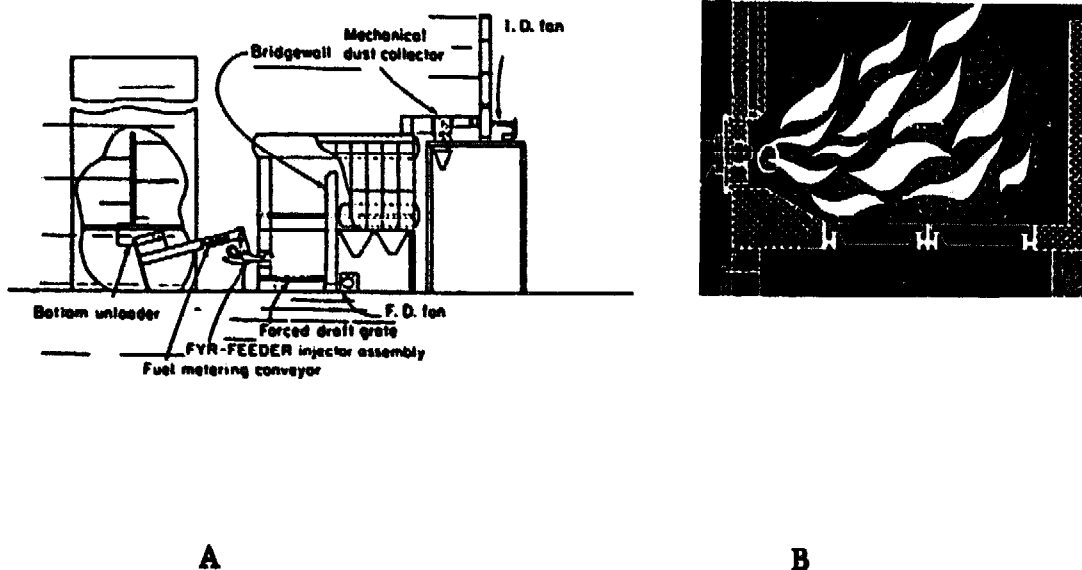
Figure 1.7 A. A typical arrangement for a complete combustion system with a spreader stoker (32)

B. A detail of the spreader stoker (19)

This system is built by the American Fyr-Feeder Engineers, at Des Plaines (Ill., USA) (36). A German version is the Medioplan, made by Mittelmann und Stephan at Laasphe (FRG) (16). See figure 1.8.

outlet to atmosphere
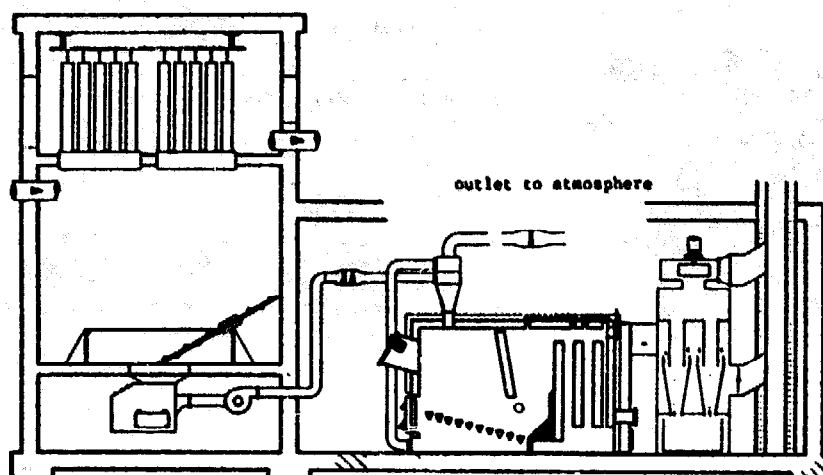
Figure 1.8 The Medio combustor (16)

c) THE SUSPENSION COMBUSTORS

During the 1960's, cyclonic-type furnaces appeared that could burn sawdust for steam raising. In the most usual type, pneumatically conveyed sawdust was blown tangentially into the upper section of a cylindrical combustion chamber (the vortex chamber), thereby creating a strong swirl, which on encountering the high temperatures, resulted in rapid combustion. These furnaces were designed to burn only fine particle-like wood residues, mostly with a low moisture content (13). Some will burn sawdust of up to 45% humidity of weight.

d) THE FLUIDIZED-BED COMBUSTORS

Fluidized or moving bed systems usually employ a bed of hot sand, onto which the sawdust is fed. Air is blown through distributors, located at the base of the bed, to cause a violent motion of the sand and wood particles. The wood material undergoes dehydration, carbonization, gasification and combustion within the bed. Energy is provided

Advantages of Fluid Bed Incinerators for Waste Wood Combustion
1. Burns green hogged wood waste without expensive predrying or pulverizing—2-inch cubes or finer—up to 55% moisture/45% bone dry wood.
2. Combustion of wood is self-sustaining. No supplemental fuel is required after brief startup.
3. Unique automatic oil or gas-fired standby system.
4. Boiler efficiency comparable to oil- or gas-fired equipment.
5. Factory prefabricated modular construction reduces onsite erection time, which can result in substantial savings in construction labor costs.
6. Stack emissions generally meet air pollution requirements.
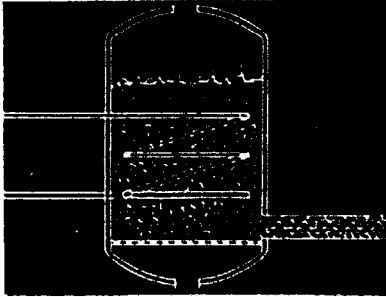
Figure 1.9A   The fluidized-bed system (19,6)

In the form of a hot gas, which can be utilized in an integrated boiler, or by an exchanger in the bed (6,13,19). The velocity of the blown air is a function of the size, shape and density of the bed medium. Small and light particles need lower velocity than large and heavy ones.

Velocities higher than the minimum value required for fluidization do not necessarily improve operation, but can even reduce the efficiency of the fluidized bed by localized spouting, excessive bed material carryover, and a shorter time for proper combustion to take place. The minimum velocity needed, can be determined.

Since the air expands when it passes up through the heat bed, the velocity increases. When the bed is hot, less air is needed then when it is still cool. The effective air-fuel ratio depends also on the moisture content. Wetter sawdust needs less air per kg of fuel, because there is less combustible material. For an economical process the moisture content must be under 55% of weight.

Before a wood particle begins to burn, the absorbed water has to evaporate. During this time, the temperature doesn't go higher than 100°C, which is relatively cool. Much energy is lost in this way.
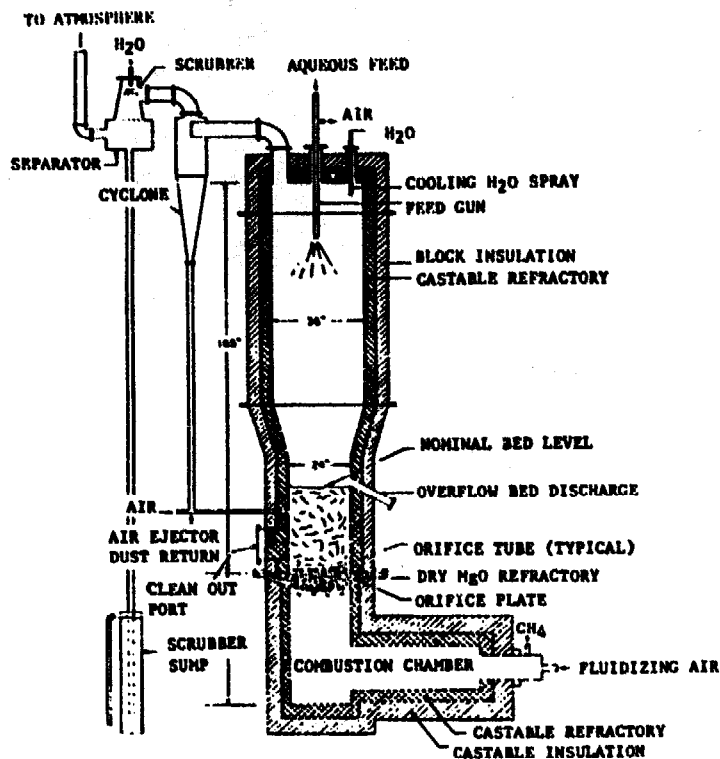
Figure 1.9B   The fluidized-bed system (1)

When the quantity of the air blown through the bed, necessary for proper moving, is less than the air needed for complete combustion, air must be added above the bed.

Capital costs of modern woodwaste-fired systems are high, because of the strong design requirements on emissions control and safety, and the automation. However, once in operation, they require minimal attention.

The energy produced by these combustors can be used for steamboilers, hot water boilers, heat exchangers (in which heat transfering oil is circulated in a closed system, at temperatures of 180-260°C), direct heating with hot combustion gases (for the kilns), and exchangers transfering heat from the hot combustion gases to the air (13).

1.2 BRIQUETS FROM SAWDUST

Sawdust in its natural form is a very bulky material with a relatively low heating value and high transport- and storagecosts. A method to get a more profitable product and to facilitate its retail value is to compress the sawdust into briquets. Figure 1.10 shows some forms of briquets.
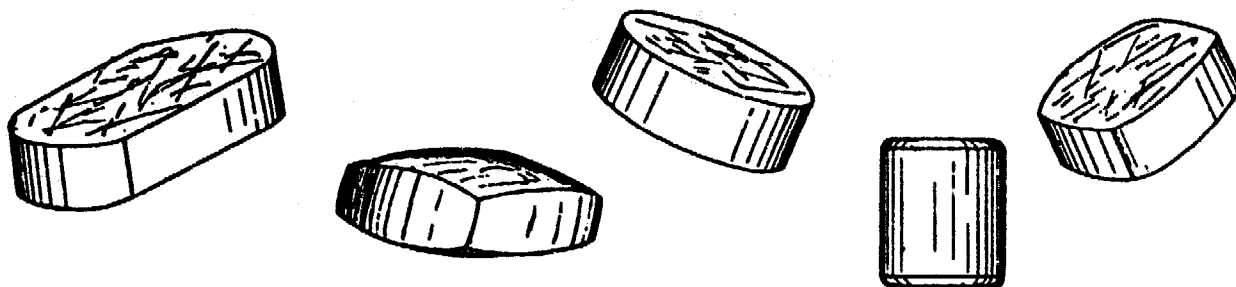
Figure 1.10   Forms of briquets (34)

Sawdust briquets are easy to kindle, give abundant heat in a short time and are very clean (18, 23). Therefore one is willing to pay the price which is comparable to that of coal. It will be clear, that the more expensive the other fuels (including solid firewood) are, the more economical it will be to make briquets of sawdust.

The briquets must have a sufficient toughness to withstand exposure to weather and shocks during transportation. During combustion, the exposure to heat must not cause disintegration (23).

For a profitable production, continuous operation is desirable. Large and continuous supply of waste must be available for industrial production, and the briquetting machinery must be located at the source of the waste (23).

The waste must have a moisture content of less than 10% to get the right strength. If the humidity is higher, the waste has to be dried in drums on steam heated plates, by steam pipes over which the waste is cascaded (23).

When there is not enough sawdust available, it should be mixed with other combustible solid waste for a profitable production. It can be mixed with bark, alfalfa, peat, coal, etc. An example is a briquetting process, which combines sawdust and coaldust with chemicals. The mixture is compressed into logs 100 mm in diameter and about 600 mm long (23).

As early as the beginning of the 19th century, people tried to make briquets from sawdust (33). First binders such as tar, resins, clay, etc. were used. However, none of these processes have attained any particular importance, because of the cost involved (4,18). In those days, briquets pressed without a binder mostly were usually not succesful, because temperature and pressure were too low. In the 1950s several economical methods were developed to make briquets without a binder (23).

1.2.1 PRESSING WITHOUT A BINDER

After the First World War, a high grade sawdust briquet was developed by the Alabama Polytechnic Institute in Auburn (USA)(23). The sawdust was preheated up to 275°C, to destroy the elasticity of the wood. This preheating also causes an evaporation of the moisture and most of the bounded oxigen and hydrogen from the wood, thus decreasing the weight with about one third and almost doubling the heating value per kg. The sawdust gets a brownish colour, because it has been partly charred. The preheated sawdust is briquetted at a pressure of about 46 MPa and a temperature of 100°C, without a binder. Moisture must be added. The obtained (semi charcoal) briquets are proof against rough handling and weathering, if protected from rainfall. According to an extensive investigation, the above mentioned temperatures and pressures give the best result (23).
It has been found later, that at temperatures above the minimum plastic temperature (163°C), wood is more or less

self-bonding. The combination of pressure, cohesion of the interfaces, interlocking of vibrous parts of the particles and possible adhesion of the heat-softened lignin, causes a binding action. The briquets have to be cooled under pressure (4).

1.2.1.a HAND PRESSES

During the Second World War, diverse hand presses were developed in Germany. Figure 1.11 shows two presses made by Rebello.

A   B
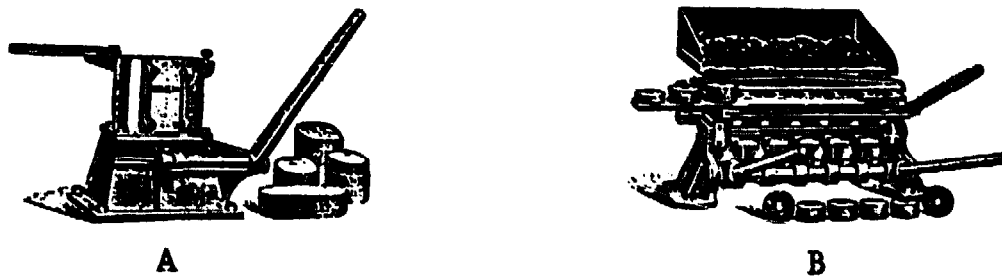
Figure 1.11 Singular (A) and plural (B) press (34)

The singular press has a capacity of 100 to 150 briquets per hour. The size of the briquets varies from 100 to 200 mm in diameter and 10 to 100 mm in thickness, depending on the press. The weight varies from 0.1 to 2 kg.

The plural press has a capacity of 600 to 650 briquets per hour, each press action delivers 6 pellets. The pellets have a diameter of 90 mm and a weight of 80 to 700 grams (34).

Figure 1.12 shows a pressing machine, which can exercise 4 to 5 times as much pressure. To reach this pressure a relative "long" time is needed. However, the machine also has the possibility to deliver low pressure briquets in a shorter time. The latter were made by means of the handwheel for quick pressing, while the high pressure briquets were made by moving the lever for high pressure pressing up and down fourteen times (34).
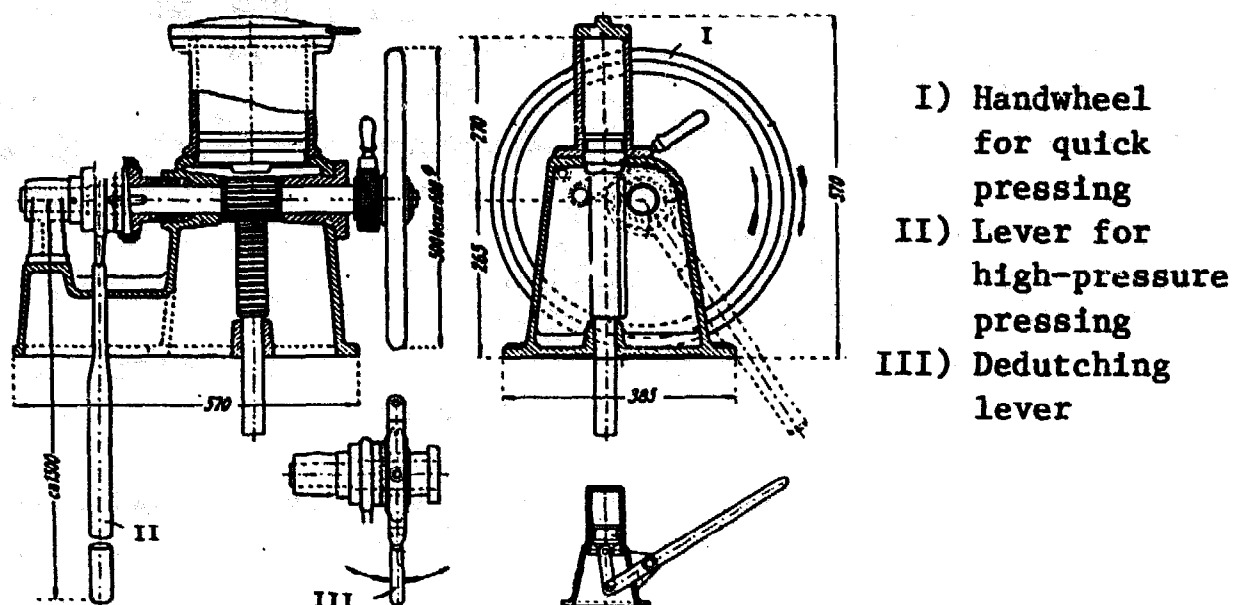
Figure 1.12 A high pressure or fast
pressure handpress (34)

I) Handwheel
for quick
pressing
II) Lever for
high-pressure
pressing
III) Dedutching
lever

1.2.1.b APPLIED COMPACTION MACHINES (INDIA)

After the world-wide energy crisis, the School of Applied
Research, Vishrambag at Langli (India), developed three
versions of compaction machines: one operated manually, one
operated by bullock and a mechanically operated one. Besides
sawdust, also agricultural wastes can be compacted with these
(2).

The manual version is specially useful for individuals or
families in rural areas. The hand press can provide poor
families with domestic fuel. By selling the fabricated
briquets they do not need themselves, they can earn their
livings. The manually operated press works on the principle
of a reciprocating engine. It consists of a flywheel, to be
rotated by hand, mounted on a crank-shaft with bearings on
both ends. The crank-shaft drives a plunger to compress the
waste into briquets with a diameter of about 30 mm and 10 mm
thick. The rate of production is about 25 briquets per minute
or over 6 kg per hour.

The bullock version can be used by farmers during the time of
the year when they do not need their bullocks for normal
farmwork. The press, operated by a single bullock, has two
sets of dies and punches, which are activated as the animal
rotates, by two sets of simple side and face cams, driven by
a central shaft. The machine is fed automatically, and has a
rotation speed of about 4 rpm. The output is 2 briquets per
revolution, each briquet weighing 30 to 50 grams, depending
upon the diameter of the used die (50 mm or 60 mm) and the
used agrowaste. The capacity is about 20-25 kg/hour.

The powered version can be used there where usable agrowastes
are available in large quantities. This machine is driven by
an AC motor.

1.2.1.c AUTOMOTIVE COMPACTION MACHINES

To process large quantities of sawdust etc. an automotive
pressing machines can be used.
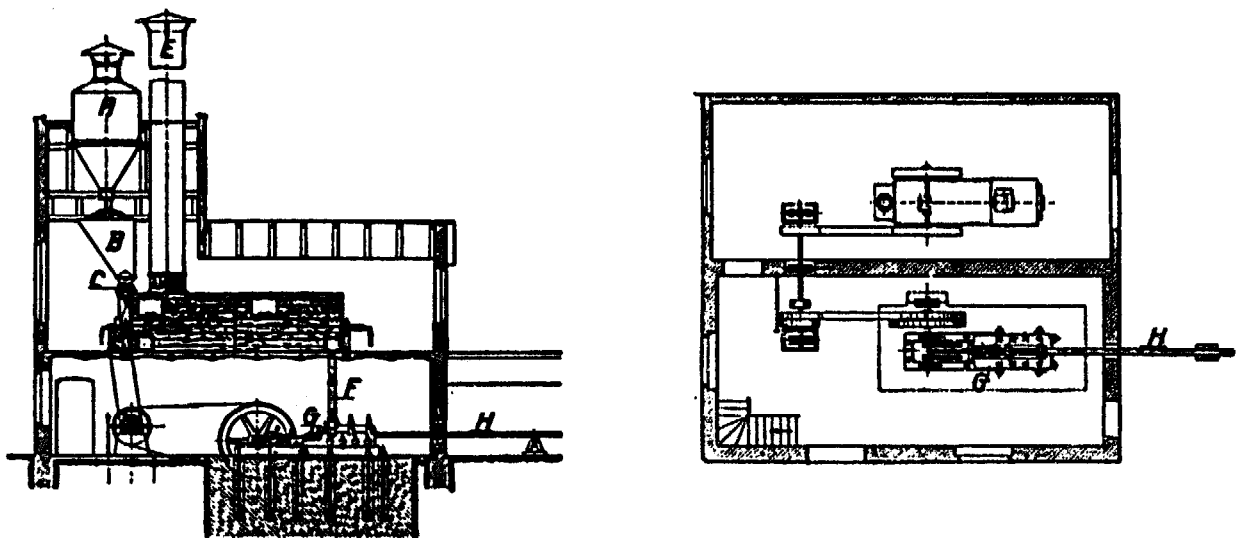
Figure 1.13 Sawdust pressing plant (34)

Figure 1.13 on the foregoing page shows such an automotive pressing machine, made in Germany before World War II. From the feedhopper B, the sawdust is carried to the drier D. The evaporated water leaves the drier through the stack E, while the dry sawdust drops in the pelleting machine G. The pellets are carried off through a cooling gutter (34). The plant is made by Ganz & Co. at Ratibor (FRG).

In the USA a type of machine named "Pres-to-log", made by Wood Briquettes Inc., at Lewiston (Id., USA) (23) is popular. Sawdust and the finer chips are compressed in a compression chamber by means of a feedscrew, with a pressure of about 21 N/mm^2. At the outlet from this chamber, the compacted material is cut into a spiral ribbon and forced into a cylindrical hole of a mold, under a local pressure of 175 to 210 MPa. The friction at this pressure generates sufficient heat to produce the necessary plasticity for self-bonding. The molds with a diameter of about 100 mm are spaced at regular intervals in and extending through the rim of a large wheel (about 300 mm in diameter). The axes of the molds are parallel to the axis of the wheel. The bottom of the mold cavity is closed by a hydraulically operated piston. The piston retracks during filling and supplies the necessary resistance. The water cooled moldwheel revolves to bring the next mold into line for filling. The resistance piston ejectes the cooled briquet before the mold reaches the fill location. The 100 by 300 mm briquets are suitable for handfiring. The production rate is about 500 kg/hour. One man can handle two machines (23).

In case of mechanical stoking there is a machine available that extrudes the selfbonded material through a cluster of eight 25 mm wide round holes, to form continuous rods, which are cut by rotating knives into pellets with a length of 25 mm. The production rate is about 800 kg/hour (23).

In a Swiss patent, the "Glomera" process, briquets are compressed under a pressure of 120 MPa. The sawdust is forced by pistons or rams. The adjustable slight taper provides sufficient resistance to the flow of the material to develop high pressure under the pistons and thus causing the necessary heat. Since the cohesion between the successive charges is less than the cohesion within each charge, the briquets tend to separate into disks. The obtained pellets have a diameter of about 80 to 90 mm and are about 6 to 25 mm thick. The double delivery briquet-press produces 100 to 120 briquets a minute or 1 ton per hour, and can be tend by one man. The pellets are not very suitable for mechanical stoking. In newer models, the charges are precompressed to give greater density (18,23).

An American extrusion machine with 8 or 16 tubes, developed by W.W. Letts from Northvill (N.Y., USA) and manufactured by Landy Hill Iron and Brass Works at Hudron Falls (N.Y., USA), produces longer pellets. The pressure face of the piston has a dimpled center and scalloped radial grooves, for a greater interlocking between the successive loads. One man can supervise four 8-tube machines, with a total production grade of 1.2 to 1.8 tons/hour (23).

In a process used by the California Pellet Mill Co. of San Fransisco (Ca., USA), the hogged wood waste is fed into a die cup with tapering orifices in its bottom. A roller in the bottom of the die cup, revolving under heavy pressure, forces the material through the orifices to form rods of dense material which are cut into short lengths by a rotating knife under the die cup. This machine has a production of about 2000 kg/hour (23).

Recently developed presses are the Turbo briquetting press (made by Weima in the FRG), the German "Spänex" briquetting press and the "Volmac" briquetting press from "Tukker Houtbewerkingsmachines" in Amersfoort, The Netherlands. The latter produces very dense briquets with a density of 1400 kg/m³ and a heat value of 17 to 18 MJ/kg (16).

1.2.2. PRESSING WITH A BINDER

When briquets are made with a binder, the binder must not cause smoke or gummy deposits, while dustforming should be avoided. The binder must have a heat value which is at least as high as wood (23). Environment pollution by the additions have to be avoided.

There are three classes of binders: inorganic materials (cement, sodium silicate, etc.), organic (tar, pitch, resins, glues, etc.) and fiber. Cement increases ash, decreases combustibility and disintegrates during burning. Organic binders usually increase the heat value and do not enlarge the ash quantity. Some of them do not disintegrate during combustion either. The best binders are usually too expensive for economical use. Self-contained extractable binders of wood are tars, formed in destructive distillation, and the resins in a few kinds of wood (23,34).

The so-called Müller-process makes briquets with hydrated wood fibers. These fibers should then be added in relatively small proportions to the material and subsequently compressed by a wet method combined, for economy, with air drying (33,34).

P.J. Weytmans Houthandel BV in Udenhout, The Netherlands, developed a process to make briquets consisting of 40 to 60% by weight of sawdust, 1 to 10% of zinc cinders, and the rest of Bright Stork Slackwax. The latter is a good and cleanly burning binding agent, while the cinders are added to get incombustible particles in the briquet to prevent the forming of carbonaceous crust. This crust hinders complete combustibility. As these briquets became too expensive, the production was stopped. Moreover the cinders can pollute the environment. Plants will not grow when there is too much zinc around.

1.2.3. CHARCOAL BRIQUETS

Charcoal briquets can be made either by pressing of prepared charcoal, or by carbonization of wood briquets (23).

During World War II, Basore and Moore developed a method in which dry sawdust was heated in molds, so that partial carbonization under the weight of the mold piston only, took place. Under a pressure of 2.5 MPa, the sawdust is carbonized completely. To drive off smoke-producing volatiles, the briquets must be heated further. (23).

In the so-called Seaman process, distilled sawdust is mixed with wood tar produced in the distillation pocess, and afterwards briquetted and reheated in a retort, where the lighter fractions of tar are recovered and the charcoal particles are bound firmly together. A very dense briquet results (23).

A comparable system, the so-called Licalit-process (German patent DRP 650045), was used in Germany during the second World War. Here the evaporating gases were used as fuel to drive the pelletizer. The obtained briquets do not contain sulphur and phosphor and have a heating value of 31 to 33.5 MJ/kg. These briquets are especially suited to melt high quality iron and steel (34).

1.3   CARBONIZATION OF SAWDUST

Carbonization is the conversion of wood into charcoal. When dry wood is heated to temperatures over 270°C, pyrolysis or thermal decomposition takes place to form charcoal and volatile matter.

Charcoal by pyrolisis of wood has been done for centuries. Carbonization of sawdust is a more recent idea.

Charcoal is a smokeless, clean-burning fuel and has a calorific value three times higher than wood and similar to that of high quality coal: over 30 MJ/kg. A high proportion of this energy is emitted as radiant heat. The yield of charcoal by weight is about 20 to 30% of the dry weight of the wood used, and by volumes about 50% (9).

Mixing charcoal with fuel is being studied. Table 1.1 (on page 1) gives the heating values of two mixtures in the ratio 10:90 and 20:80 by mass. This slurry fuel has been used succesfully in Australia and Papua New Guinea. However, provisions would have to be made for the selection of pumps, valves, etc. and for more frequent cleaning of fire-tubes, because charcoal/oil has a higher ash content than oil alone (13).

Besides fuel, charcoal can also be used as an absorbent (when treated with steam or chemicals, activated charcoal can be produced); as a carbon source (as rubber filler or in carbon electrodes for aluminum production); as a reducing agent (in the processing of quartzite into silicon metal) and for horticultural applications (as potting medium for orchids etc.) (12).

1.3.1. FLUIDIZED-BED CARBONIZATION

The fluidized-bed carbonization plant, recently developed by CSIRO in Australia (12,13), is a combustor to produce charcoal from sawdust and other hogged wood waste. The sawdust is fed into a sand bed, which is initially heated with preheated air up to a temperature of 500°C, and kept moving by air injection.

The sawdust dries very quickly and carbonizes into charcoal and volatile gases. The latter are burnt in the fluidized bed by blown air. The liberated heat is more than sufficient to maintain the required temperature in the bed. The process is then self sustaining without any external heat (12,13).

The light charcoal particles that are formed are lifted up by the flue gases, and by way of a cyclone separator dropped in a charcoal hopper. The lump charcoal can be recovered by screening the bed material and putting the sand back on the bed.

The energy, released by the burning of the volatiles, which is needed to maintain the required bed temperature can be used for the heating of oil in a heat exchanger, or for direct steam production. For that purpose a heat exchanger, consisting of a coil, is placed in the moving bed. The heat transfer coefficient for the bed heat exchange is very high: up to 0.47 $kW/m^2/°C$.

In the case of oil-heating: oil, circulating in the coil within a closed system, is heated to temperatures of 180 to 260°C at low pressure and used for steam production in a boiler (figure 1.14, next page).

Steam can also be produced directly. The hot steam can be used both for heat and power. The latter by running a steam engine or generation of electricity by a turbine alteration. Figure 1.15 on page 49 shows a fluidized bed system with heat recovery and electricity generation.

1   Fluidised bed
2   Sawdust hopper
3   Variabel speed DC motor
4   Bed heat exchanger
5   Arch breaker
6   Srew leeder
7   Air compressor
8   Air filter
9   Cyclone
10 Disengagement section
11 Plenum chamber
12 Porous distributor plate
13 Oil pump
14 Oil filter
15 Boiler
16 Oil expansion tank
17 Oil bypass
18 Ignition burner
19 Air preheater
20 Orifice plate
TC Thermocouple
PC Pressure drop
P   Pressure gauge

FLUE GAS

9

16

HEAT
TRANSFER
OIL

10

CHARCOAL

STEAM

2

5

SAWDUST

3

15

AIR

8

WATER

6

GAS

TC

18

AIR

1

TC

20

4

17

7

PC

20

PC

19

12

11

P

13   14

TC

Figure 1.14 Experimental fluidized-bed charcoal plant with
            hot-oil heat recovery at CSIRO Division of
            Building Research (13)
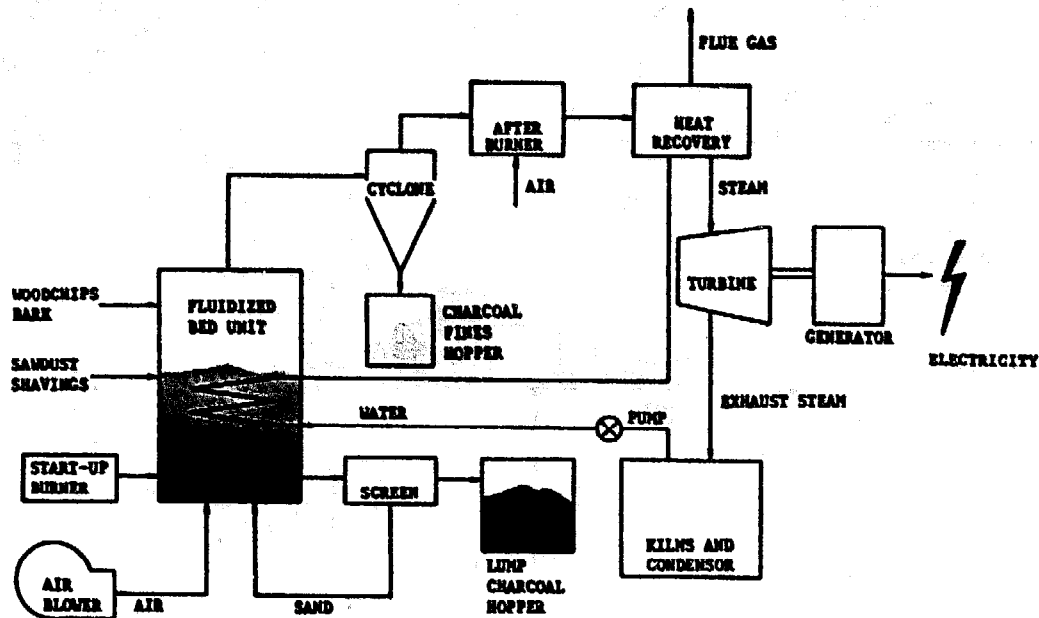
Figure 1.15 A fluidized bed system for charcoal production, heat recovery and power generation from sawdust (12)

A commercial fluidized bed plant for a typical sized sawmill with dry kilns would be designed to convert 17.000 tonnes/ year of wood waste to 2300 tonnes of charcoal. Tabel 1.4 shows the capital costs and the DCF (Discounted Cash Flow) for plants with various options (12).

Table 1.4 Capital costs and Discounted Cash Flow analysis of fluidized bed plant options

Plant Option	ECI [1]	DCF return after tax
1 Charcoal production only	$ 260 000	22 %
2 Charcoal prod. with heat recovery	$ 370 000	30 %
3 Charcoal prod. with heat recovery and electricity generation	$ 495 000	34 %

Charcoal price $ 60/tonne, disposal cost savings of $ 3.50/tonne, heat savings 0.74 c/MJ for mill's requirements of 7.5 x 10 MH (options 2 & 3), electricity price 4.74 c/kWh, annual output 2.4 GWh (option 3), plant life 15 yr.

[1] ECI= Estimated Capital Investment

1.3.2. MOBILE PYROLISIS SYSTEM

The Engineering Experiment Station in Atlanta (USA) developed a mobile pyrolysis system. The whole system is mounted on two trailers (30,32). It can be fed with sawdust and other solid combustible forestry and agricultural wastes. The end product is charcoal mixed with pyrolysis oil. The start-up would be accomplished using propane, but after that, the process is completely self-sustaining. Figure 1.16 shows the process in a flow diagram .
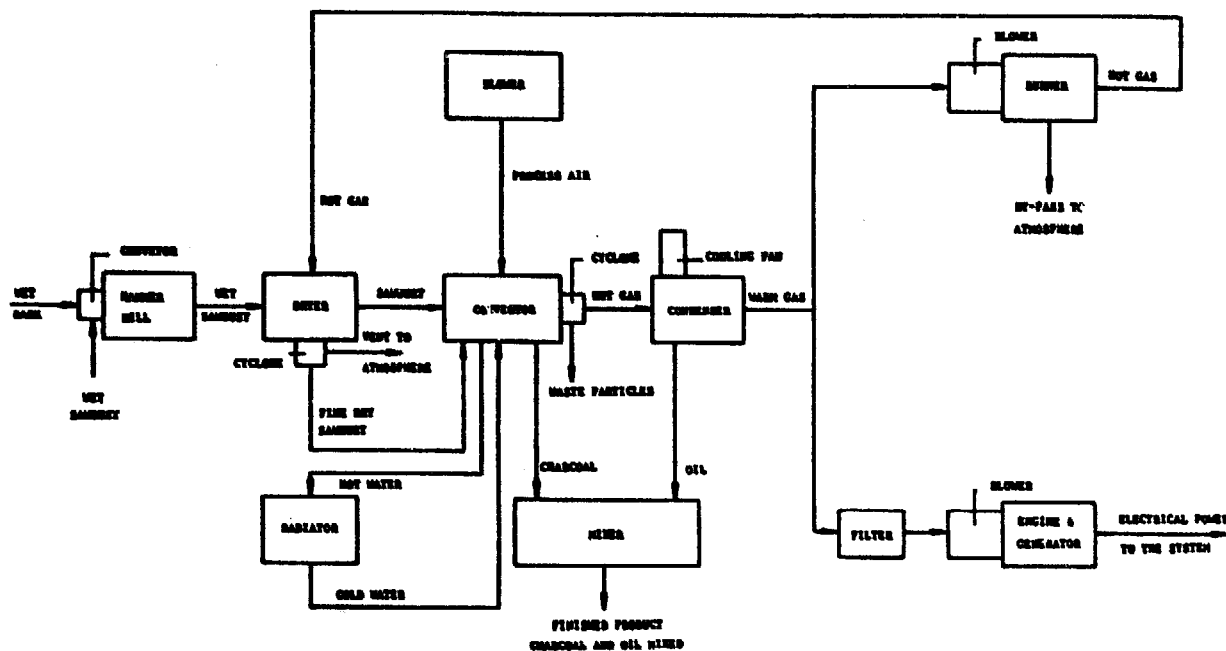
Figure 1.16 Process flow diagram of a mobile
pyrolysis unit (30)

The sawdust is put in a feedhopper or receiving unit bin by a front end loader. Coarse material needs a feedhopper with a hammer mill. The dryer is heated by a part of the hot gases, produced in the burner. After drying, the material is conveyed to the convertor. The required process air is injected by a blower. The obtained char is emptied into a mixer where it is combined with the pyrolysis oil.

The latter is separated from the off-gases in a condenser. In this condenser the temperature has to be above the off-gas dewpoint to avoid condensation of moisture. The part of the off-gases, to be used in the drier, are led through a burner to burn the combustible gases. The rest of the off-gases is used to generate electricity.

Figure 1.17 shows the plant in the operational mode. A perspective picture of an earlier version is shown in figure 1.18.

LEGEND:

1	Front end loader
2	Bin conveyor
3	Receiving bin
4	Conveyor mill
5	Hammer mill
6	Drier
7	Feed conveyor
8	Convertor
9	Cyclone
10	Condensor
11	Condensor cooling fan
12	Draft fan
13	Combustion air fan
14	Off-gas burner
15	Drier fans
16	Burner exhaust
17	Drier exhaust duct
18	Cyclone
19	Process air blower
20	Generator
21	Engine
22	Cooling water radiator
23	Compressor
24	Conveyor
25	Char oil mixer
26	Char storage bin
27	Control room
28	Agitator
29	Front and loader storage
30	Cat walk
31	Engine blower

Figure 1.17 The mobile plant in operational mode (30)
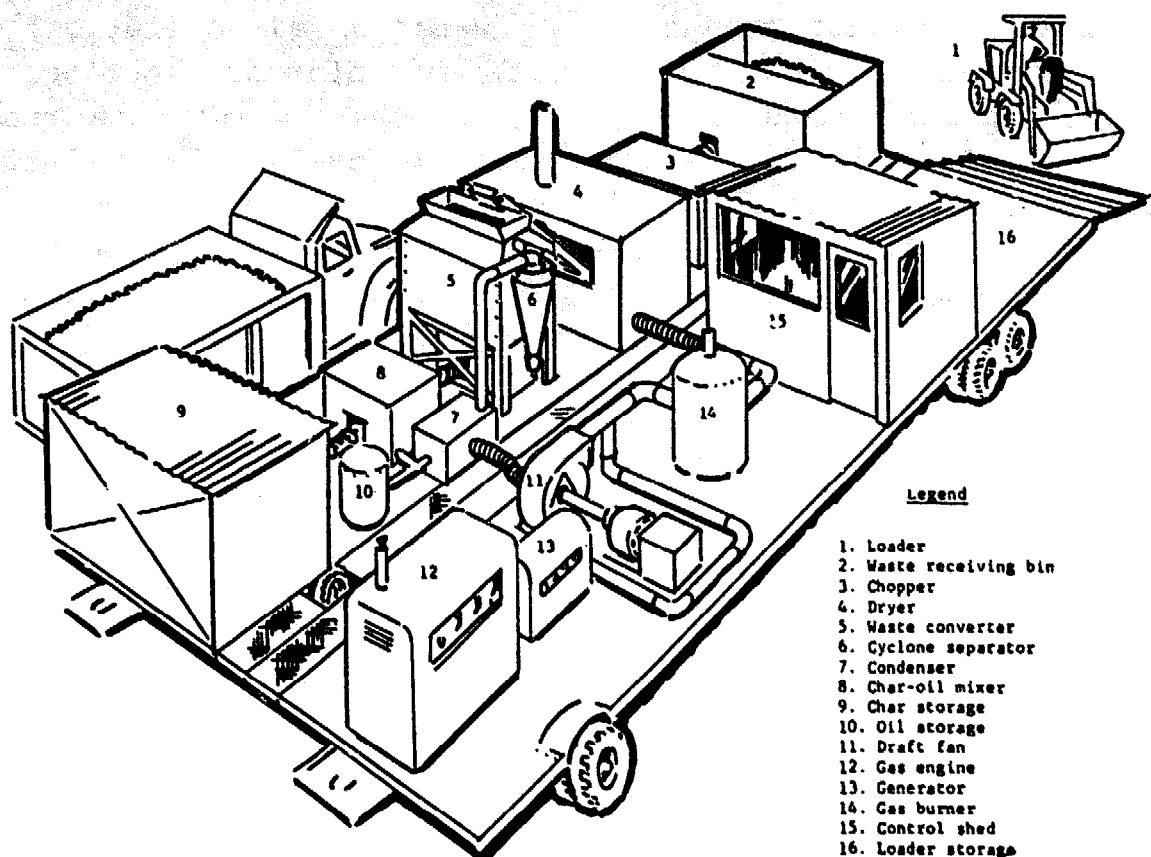
Figure 1.18 Perspective of a mobile pyrolysis waste conversion system (32)

Legend

1. Loader
2. Waste receiving bin
3. Chopper
4. Dryer
5. Waste converter
6. Cyclone separator
7. Condenser
8. Char-oil mixer
9. Char storage
10. Oil storage
11. Draft fan
12. Gas engine
13. Generator
14. Gas burner
15. Control shed
16. Loader storage

All the required components, except the char storage bin, can be placed on two trailers. For example the receiving bin can be placed above the generator and the engine, by a collapsable ramp stowed underneath. The trailers are fitted outside with metal platforms on all sides, which can be fold out to get a working space for the operating crew, consisting of two men, and local filler personnel.

Since a ceramic insulator for the convertor is very heavy and fragile, the necessary insulation is obtained by making "char shelves" on the innerside of the convertor walls. These shelves will catch enough downward moving material to form a good insulator because of its relatively low conductivity. A fibrous insulator is used as a back-up system.

The plant does not produce land, water or air pollution, nor does it require any external source of water for cooling. One kg of dry feed produces 0.456 kg of charcoal mixture with a heating value of 27 MJ/kg. An economic analysis showed that, even if the price of the produced fuel is low, the system will operate profitably. The system has a capacity of 200 ton of sawdust per day, with a humidity of 50%. To obtain a maximum economic benefit, the system should operate 24 hours a day, 5 days a week (30).

1.4 GASIFICATION OF SAWDUST

Besides carbonization, sawdust can also be converted in the
so-called gen-gas. Gen-gas can be used for heating, but also
as fuel for an internal-combustion engine. Especially in those
cases where it can be used to replace or to complement oil or
gas in existing boilers or engines, gasification offers great
potential (36). Gasification will be of very great interest to
small users, since the total system costs of a gasification
installation is less than those of a direct combustion unit,
including the pollution control equipment. Gasifiers generally
burn cleaner than direct combustors. In small units, using
gen-gas, mechanical power generated by an internal-combustion
engine is far cheaper in both investment and operation costs
than the production of energy by means of steam generation
(39).

Gen-gas has a low heating value. Gasification with pure oxygen
instead of air gives a gas with a medium heating value (5).
Table 1.5 gives an indication of the composition of a normal
gen-gas.

Table 1.5 Composition and heat value of gen-gas (39)

Carbon monoxide	CO	20 to 25%	average 23%
Hydrogen	H_2	10 to 25%	average 15%
Methane	CH_4	0 to 4%	average 2%
Carbon dioxide	CO_2	2 to 15%	average 10%
Nitrogen	N_2	45 to 60%	average 50%

Net calorific value, 4.2 to 5.7, average 4.8 MJ/Nm^3

A schematic diagram for a so-called pyrolysis-gasification-
combustion process is shown in figure 1.19. The flow of any
gas steam (and its enthalpy) is designated H (Heat loss is
designated Q). The produced steam (H_{13}) of the boiler can be
used to drive a turbine (not shown) and is, after condensa-
tion, returned to the system as boiler feed water (H_{10}) (5).
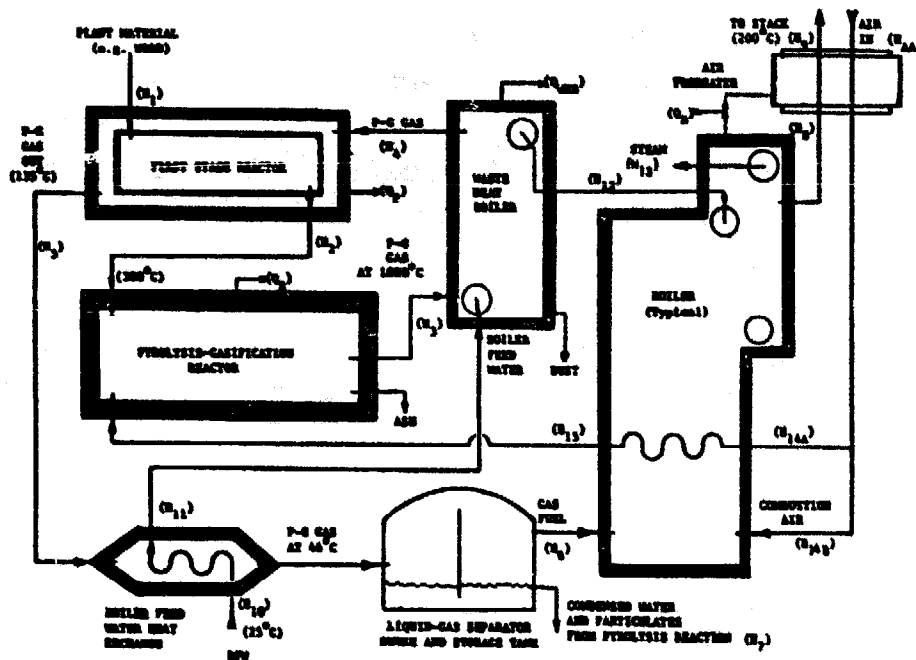
Figure 1.19 Pyrolysis-gasification-combustion process (5,28)

A gasification system looks almost the same as a direct combustion unit. However, the fuel has to be fed into the combustor through an airlock feeder, to prevent the introduction of air above the fuel bed, for this will convert the carbon monoxide into carbon dioxide and even create the risk of an explosion (36). A possible airlock feeder is a "revolving door".

1.4.1 FIXED-BED GASIFIER

The American Fyr-Feeder Engineers in Des Plaines (Ill., USA), developed a fixed-bed gasifier. Figure 2.20 shows the system. To start the gasification, a small amount of fuel is ignited at the bottom of the reactor, to create the continuous gasification. The airtight unit should be completely filled. The required air is injected through the bottom of the grate, to support the oxidation reaction (36).

Rotary
Airlock
Fuel
Feed

1% Methane
6% Carbon Dioxide
50% Nitrogen
30% Carbon Monoxide
10% Hydrogen
3% Tars & Oils

Distillation

Reduction

Oxidation

Ash Zone

Primary Air
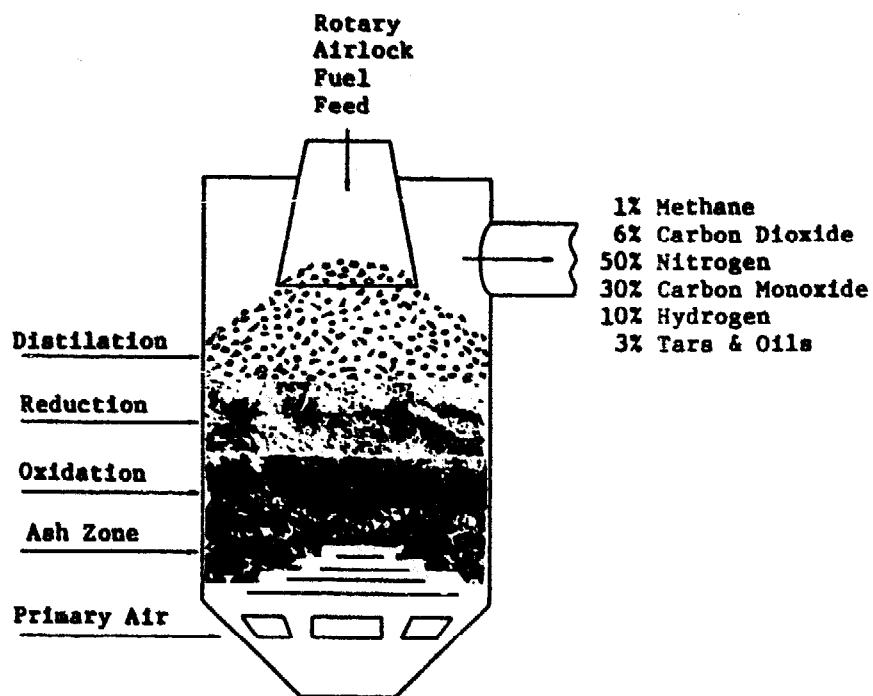
Figure 1.20 Simplified American Fyr-Feeder
wood gasification system (36)

If necessary the process can easily be stopped for a period of several hours. As long as the carbonized bed is maintained, the gasification will be continued immediately, as soon as the air is reinjected through the bed. The carbonized bed has a temperature of about 900°C (36).

Since the flue gas contains tars, the temperature must be kept in excess of 200°C therefore the distance between the reactor and the boiler is limited. However, to apply gas in an engine-generator, the gas has to be cooled in order to protect the engine, in spite of the then ocurring loss of energy in the tars and oils (36).

A commercial gasifier requires a complete combustion control panel including thermocouples for temperature monitoring and control (36,39).

1.4.2 CO-CURRENT BED GASIFIER

The Energy Equipment Engineering B.V., Oldenzaal, is the Dutch manufacturer of a co-current bed gasifier, developed at the Twente University of Technology in Enschede, the Netherlands. It is called the EEE-wood gasifier, and has been patented. In co-operation with SIDO in Arusha, Tanzania, an appropriate version is developed, which could be manufactured cheaper in developing countries (29).
The system is shown in figure 1.21.

d: drying zone
p: pyrolysis zone
o: oxidation zone
r: reduction zone
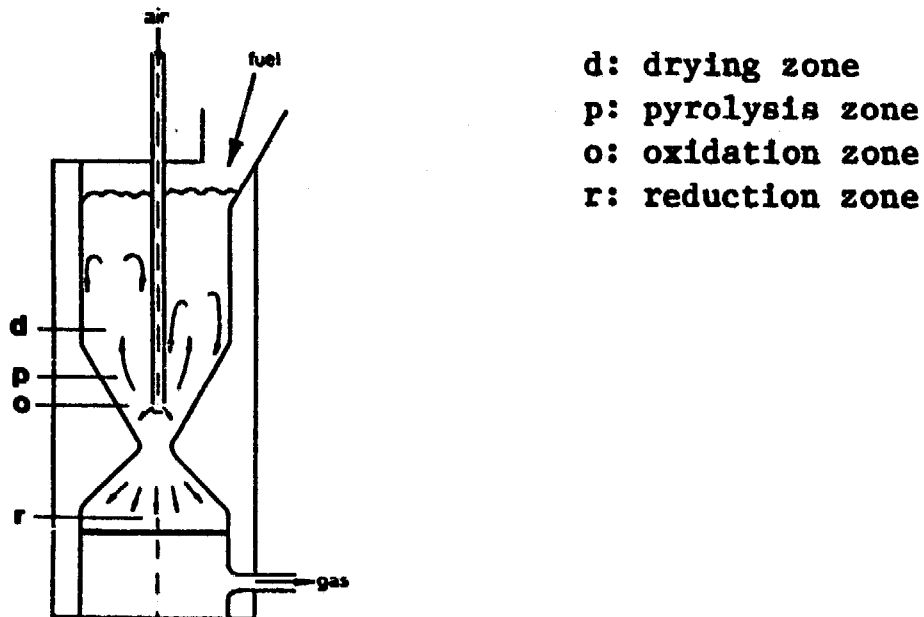
Figure 1.21 Co-current gasifier (14)

The solid material (such as sawdust, but also other hogged forestry or agricultural waste) is dropped at the top of the gasifier through an airlock feeder. A small amount of air leakage is tolerated. Due to the heat transfer from the hot lower zones of the reactor, the waste is dried. The dried material sinks to the pyrolysis zone and starts pyrolysing at 250°C, producing char and gases. Near the air inlet highly exothermic reactions take place, which result in a sharp rise

in temperature, up to 1200 to 1600°C. In this zone all the condensable gases (oils, tar) are converted and oxidized, due to the high temperature (14).

The air velocity must be precisely chosen, in order to prevent cold spots, where tar could pass uncracked. To avoid this, the cross- sectional area is reduced and the air is spread across the whole cross-section. Figure 1.22 shows three methods to spread
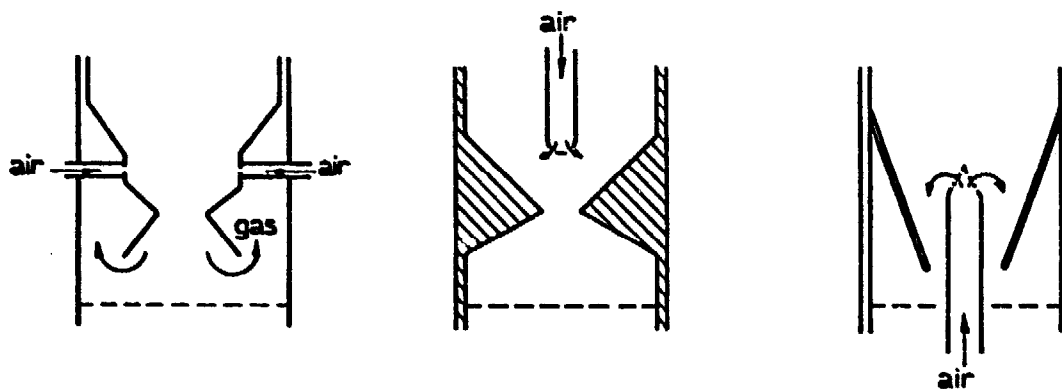
Figure 1.22 Oxidation zone with differently positioned air inlet points (14)

the air. Although the throat can hinder the solid flows, it is the best way to get a tar-free gas. A central air inlet tube from the top can be used for stirring the bed. A combination of a central air inlet with wall inlets does not give better results, while it also hinders a good control of the just air quantity at all points.

In the lower and last zone, the heat is absorbed in the endo-thermic reactions between carbon in the charcoal, water and carbon dioxide. This results in the production of a hydrogen- and carbon monoxide-containing fuel gas.

Whether a grid is necessary, depends on the amount of ash produced and its melting point, which on its turn depends on the sort of waste. Clean wood waste usually delivers a very small quantity of ash, so that a grid is not needed. The fuel gas, with a temperature of about 700°C, leaves the reactor by means of an engine or a ventilator. The gas contains some

dust, but is almost tar-free. After dust removal, it can be used for heating boilers, driving gas turbines, or, after cooling, as fuel for internal combustion engines (14).

1.4.3 THE FLUIDIZED-BED SYSTEM

In Morgantown, West-Virginia, USA, university researchers employed a fluidized-bed system for sawdust gasification. The fluidized-bed chamber is filled with sand, to a height of about 750 mm, on an perforated stainless steel sheet. The sawdust is injected by a screw feeder, about 130 mm above the grid plate. Beneath the sheet, gases are burned. The hot combustion gases are blown through the plate and the sand-sawdust bed. In operation the bed expands to a height of about 1070 to 1220 mm. Over 80% of the energy, contained by sawdust, is converted into an excellent fuel gas. This gas contains over 12.4% methane and up to 4.7% higher hydrocarbons with a heating value of 10.5 to 15 MJ/Nm^3 (27).

1.4.4 THE IMBERT STATIONARY AND MOBILE GASIFIERS

Imbert-Energietechnik GmbH & Co. K G in Weilerwist, FRG, developed a mobile woodgas power station for small users and a larger one of the stationary type, suited especially for a mixture of sawdust and coarser hogged wood waste, to achieve a high efficiency and safe operation (38,39).
A complete mobile unit consists of a gasifier (1), a gas cleaning unit (2), a gas internal combustion engine (3), an alternator (4) and an electric switchbord (5) (see figure 1.23A).

<table>
<tr><td>1 FUEL TANK</td><td>6 DUST EXCLUDER</td></tr>
<tr><td>2 FUEL FEEDER DUCT</td><td>7 CHASSIS</td></tr>
<tr><td>3 HYDRAULIC CONTROL UNIT</td><td>8 CONDENSOR</td></tr>
<tr><td>4 CARBURETTOR</td><td>9 CARBURETTOR</td></tr>
<tr><td>5 SWITCH BOARD</td><td>10 ELECTROSTATIC FILTER</td></tr>
</table>

1 GASIFIER   6 CYCLONE
2 GAS COOLING & CLEANING
3 ENGINE
4 E-GENERATOR-ENGINE
5 SWITCH BOARD

A   B
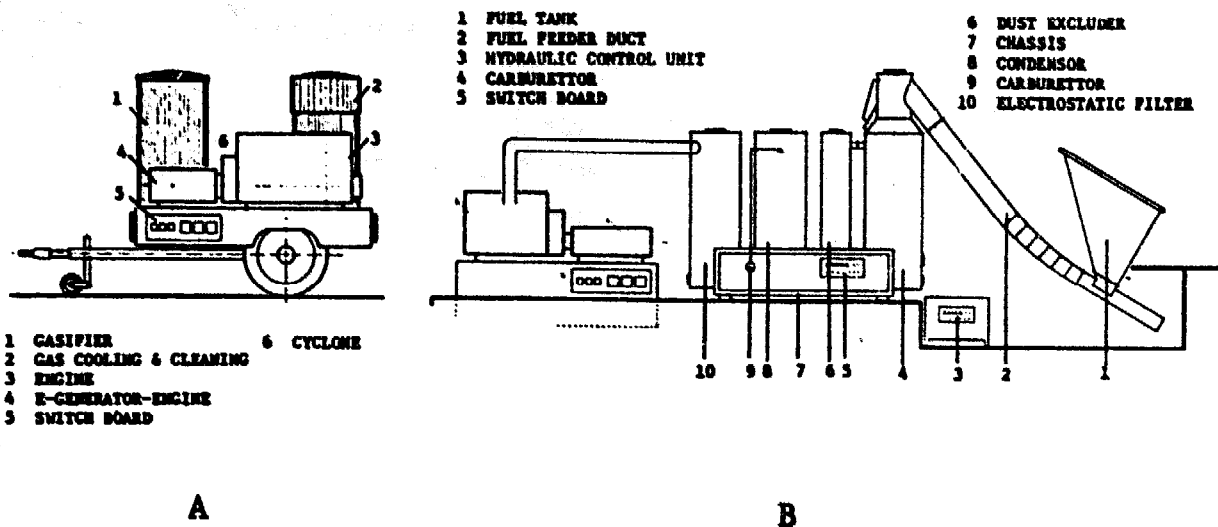
Figure 1.23 A mobile powerstation (A) and a
            powerstation of the stationary
            type (B) made by Imbert (38)

Figure 1.23B shows a complete powerplant of the stationary type. On the right hand side is the gasification unit, where the wood waste is converted into a clean gen-gas, and on the left hand side is the power unit for electricity generation.
1 kilo woodwaste gives an average of 2.2 Nm^3 gen-gas, about 0.83 kWh electricity and replaces about 0.3 kilo diesel fuel. The engines of both installations are of the suction-type; they suck the gas through the gas-air-mixers after start-up. The constant low pressure increases the efficiency of the gas engines and improves regulation. The liberated heat of the gascooler, and the generator-engine can be used to dry the waste and for heating. At larger plants, turbo operation is possible as well, resulting in higher efficiency (39).

1.4.5 THE LAMBIOTTE GASIFIER

Lambiotte & Cie. in Belgium has developed a gasifier which can
be fed with sawdust. The obtained gen-gas is free from tar and
dust. A part of the gas recirculates through the installation
by way of a ventilator. The rest is sucked out of the reactor
by a fan or an engine of the suction type. The supply of air
is accomplished by the suction of the gen-gas. A reactor with
a height of 5 to 6 m and a diameter of 1 m, can drive an
engine of about 40 kW. The heating value of the gas is about
5.2 MJ/Nm^3. Figure 1.24 shows a schema of this gasifier (21).

1.4.6 THE GUNNERMAN GASIFIER

The gasifier shown in figure 1.25 is developed by Rudolf
Wilhelm Gunnerman at Eugene (USA), and gives a gen-gas with a
heating value of 3 to 4 times that of the used waste fuel. The
gasifier is fed by pellets, made from sawdust, chips, straw,
paper, fog-peat and/or other combustable solid waste. The
pellets have a cylindrical or parallelepiped shape, with a
maximum dimension of 25.5 mm, and a minimum dimension of c. 3
mm (in each arbitrary direction), and a density of about 1.0
to 1.4 ton/m^3 at a humidity of 13% of weight. Before pressing
to pellets, the waste must preferably have a humidity of about
20-24%. The pelleting temperature amounts to 163 to 177°C
(15).
The pellets are fed into the gasifier, through an airlock
feeder, and form a conical fuel bed in the reactor. Air is
injected through a perforated stainless steel sheet. The holes
are uniformly spread over the sheet, except at the edge, to
give a uniform air current. The sheet supports the fuel, while
the non-perforated edge serves to form an insulating layer of
non burned material. The furnace has a temperature of about
1650 to 1900°C, but at the minimum about 1500°C. At these

drying zone

carbonization
zone

gasification
zone
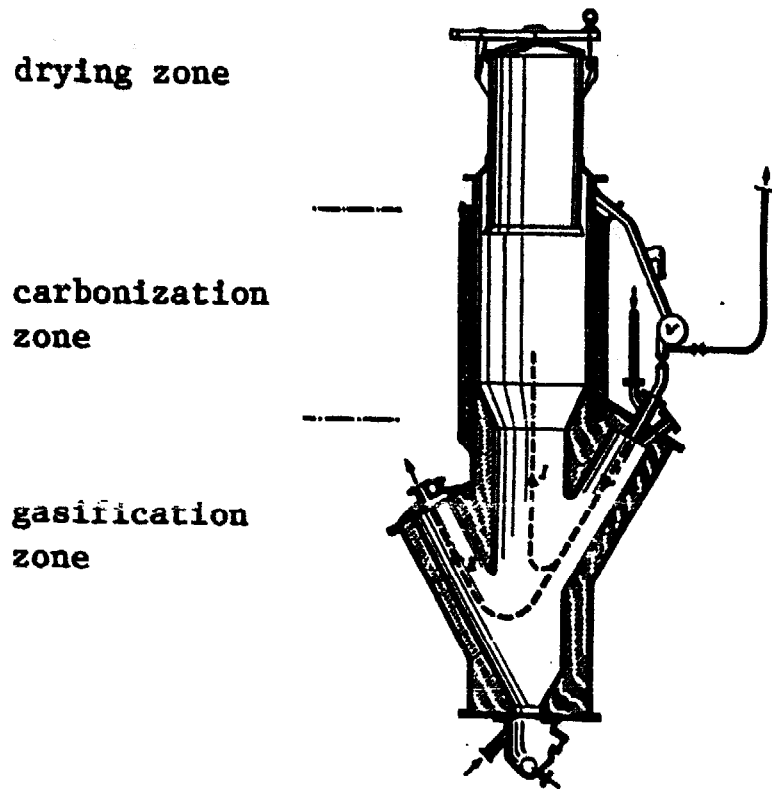
Figure 1.24 The Lambiotte & Cie gasifier (21)
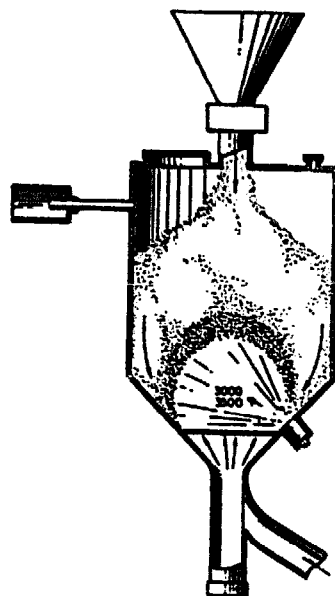
Figure 1.25 The Gunnerman gasifier (15)

high temperatures a combustible gas is formed containing carbon, hydrogen and nitrogen compounds. It is assumed that the latter cause the great heating value of the gen-gas. The nitrogen in the air reacts with the calcium, potassium and the inorganic salt of the ashes, so the amount of remaining ashes is nil (15).

1.4.7 AN URBAN WASTE-WOOD WASTE BLEND GASIFIER

Union Carbide Corporation in Farrytown (N.Y., USA), developed the Purox™ pyrolysis system, to gasify urban waste, blended with wood waste. In this manner a useful feedstock is created, because the problems of each individual waste can be minimized (the moisture content of the wood waste and the inorganic content of municipal solid waste). This could be an interesting idea, if there is not enough sawdust to make burning it economically feasible. However,if the waste water is not treated some water pollution will occur (31).

1.5 CONCLUSION

In the preceding chapter four types of possible uses of sawdust and its technologies have been discussed i.e. direct combustion, briquets from sawdust, carbonization and gasification.

The state of art of the different uses and techniques varies considerably. Direct combustion and briquetting is already common practice in many places in the Third World.

Modern carbonization and gasification techniques tend of course, to be more capital- and management-intensive. Some of these techniques are still in the research or fieldtesting phase.

From the point of view of appropriate and intermediate technology, direct combustion techniques could be given more attention. Although several sawdust-stoves are already in domestic use, there is room for improvement.

Direct combustion for industrial purposes may well be viable in certain circumstances. The most obvious application seems to be the supply of energy for the sawmill itself.

Briquetting of sawdust also may be attractive for developing countries. This applies for handpresses as well as for automative compaction machines.

When sawdust has been briquetted the material bulk has been considerably reduced to a manageable form, which reduces transportation costs -compared to those of sawdust in its natural form- considerably.

Carbonization and gasification should not be left out when considering possible uses of sawdust. However, capital and infrastructural investments are on the whole relatively high.

Besides heating or conversion of sawdust into more valuable fuels, the heat can also be used to produce hot water, steam and thermal fluid. It is also possible to convert the obtained energy into power and/or electricity.

In Appendix A some briquetpressing equipment suppliers are
mentioned, while Appendix B shows the combustion equipment.

More information about gasifiers and combustion equipment can
be found in "Gasifiers for wood and agricultural residues" by
H.E. Huynink (TOOL, Amsterdam 1982).

APPENDIX A

A.   SOME BRIQUETPRESSING EQUIPMENT SUPPLIERS

COMPRIMA Visser Tuinbouwtechniek & Hout B.V.	's-Gravendeel (NL)
B.V. Machinehandel HOLSCAN	Oudewater (NL)
HOLZMAG Holzmaschinen AG	Basel (Sw)
PIPETTA Technica Industriale	Pinerolo (It)
SPANEX Wilhelm & Sander GMBH	Uslar (FGR)
Wilhelm & Sander Benelux B.V.	Putten (NL)
De Groot Houtbewerkingsmachines B.V.	Rosmalen (NL)
P.J. Weytmans Houthandel B.V.	Udenhout (NL)

APPENDIX B

B.1   SOME COMBUSTION EQUIPMENT SUPPLIERS IN WESTERN EUROPE

FREECAL ELBOMA	Gent (B)	HST
EWI-THERM		
Wilcon Stooktechniek B.V.	Montfoort (NL)	H
KARA Reinders Almelo	Almelo (NL)	H
SPANEX		
Wilhelm & Sander GMBH	Uslar (FGR)	HST
Wilhelm & Sander Benelux B.V.	Putten (NL)	HST
De Groot Houtbewerkingsmachines B.V.	Rosmalen (NL)	HST

TWIN-HEAT Enespa B.V.	Anna Paulowna (NL)	H
VIJNCKE pvba Vijncke-warmtechniek	Harelbeke (B)	HST
VIJNCKE Brugmans	Gorinchem (NL)	HST

H = heating   S = Steam   T = Thermal (fluid)

B.2 PARTIAL LISTING OF WOOD-FIRED COMBUSTION EQUIPMENT SUPPLIERS IN THE USA (6)

Babcock and Wilcox Co. (Barberton, OH)	FE[a] PB[b]
Bigelow Company (New Haven, CT)	PB
Combustion Engineering, Inc. (Windsor, CT)	FE PB
Detroit Stoker CO. (Monroe, MI)	FE
Foster Wheeler Energy Corp. (Livingston, NJ)	PB
Hoffman Combustion Engineer. (Lincoln Park, MI)	PB
A.F. Holman Boiler Works, Inc. (Dallas, TX)	PB
Industrial Boiler Co. (Thomesville, GA)	PB
International Boiler Works Co. (E. Stroudsburg, PA)	FE
Peabody Engineering Corp. (Stamford, CT)	FE
Riley Stoker Corp. (Worcester, MA)	FE
Zurn Industries, Inc. (Erie, PA)	PB

[a]FE: Field erected: conventional wood-fired steam generators and firing equipment.
[b]PB: Packaged boilers: small factory built units that are hauled to the site intact.

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2

AGRICULTURAL USES OF SAWDUST

ir g.j. arends

2. AGRICULTURAL USES OF SAWDUST

INTRODUCTION

Since sawdust is an organic material, it will be obvious that man has tried to find profitable agricultural uses for this waste. In this chapter a survey of such uses will be given. Semi-agricultural uses will be described as well.

Generally the transport costs of will be the greatest problem In ordinary use the total costs should be lower than those of comparable prducts. To farms and other larger users, sawdust can be transported in bulk (12).

However, there are also many small customers who can use sawdust, but for whom it is not profitable to get it delivered in bulk. Therefore, it must be conveniently packed,
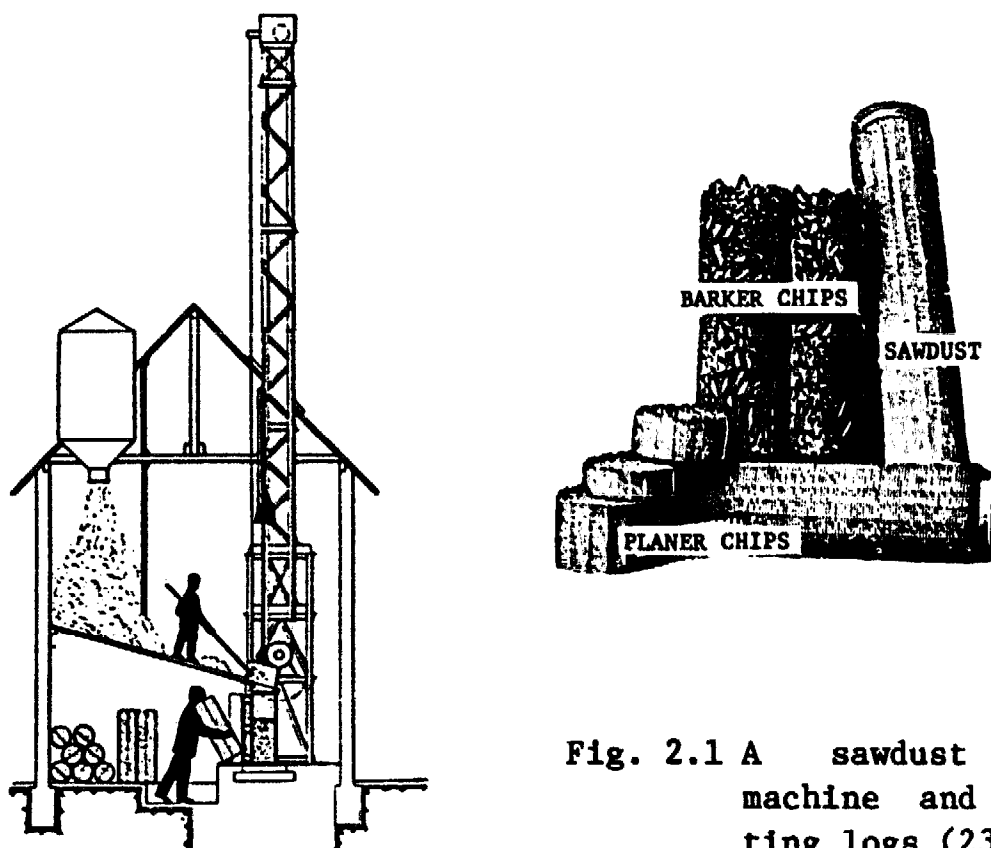
Fig. 2.1 A sawdust compaction machine and the resulting logs (23)

for instance wrapped in paper packages or sealed in plastic foil (12,13).

Picture 2.1 shows a simple compaction machine, made by Masch. Fabr. A. Bezner in Ravensburg (Germany). It consists of a 8 to 14 m high installation, in the top of which hangs a heavy weight.

Below the installation consists of two cylinders. One cylinder is filled with sawdust. After filling the weight falls down, thus pressing the filled cylinder. At the same time the other one is unloaded. The formed logs have to be covered by small boards on both ends and bound with cord or wire. The logs are about 1 m long and have a weight of approx. 20 to 40 kg, depending on the diameter and the pressure (23).

In the following we will treat successively sawdust as litter (2.1), sawdust as fertilizer and soil conditioner (2.2) and feed from sawdust (2.3).

2.1 SAWDUST AS LITTER

In several areas sawdust is used as animal litter. Sawdust absorbs liquids very well and gives a clean and warm type of litter (12,13,15,24,25).

Some poultry farmers prefer woodchips to sawdust as sawdust is dusty and tends to cake together. Many poultry farmers use both shavings and sawdust (10,15). Using sawdust instead of straw in a poultry house with a run provides cleaner eggs.

Softwood and other light-coloured sawdust is preferred by some poultry farmers, because dark-coloured sawdust can contain substances which could cause tainting. The risk of tainting is low, though (15). Other farmers prefer hardwood material with equal amounts of potash and nitrogen, to get a good fertilizer for tomatoes, gooseberries, etc. (10).

Sawdust used as bedding for animals or poultry absorbs liquid manure, which contains 90% of the total nitrogen in manure, in addition to carrying the solid manure. If 2.5 % of superphosphate is added, this nitrogen will not evaporate and a good fertilizer can be obtained (21).

2.1.1 THE DEEPLITTER POULTRY SYSTEM

In a temperate climate, the deeplitter poultry system is an economic method of converting sawdust and shavings into an usable compost. In this system, the bacteria grab the fierce ammonium carbonate to form bodies and satisfy their needs, breaking down the celluloses, hemicelluloses and some of the lignins in the bedding material, producing just as much heat as if they actually burnt it, and needing the same amount of oxygen. It will be clear that ventilation is very important. The poultry manure dries because of the heat that is produced and becomes a very useful fertilizer (10).

However, this deeplitter system appears to be not practical in the tropical areas. In Zambia an appropriate deeplitter system was developed. The best results were obtained in a

poultry house for 200 birds, with a length of 18.30 m and 3.65 m wide, the long side sited from east to west.

This orientation allows the morning and afternoon sun to shine on the ends of the house, while the birds are shaded from the hot midday sun (10).

The walls are 1.83 m high. The lower part of the wall, up to 0.61 m, is closed, while the upper part consists of wire netting and has good and ample ventilation. The roof is supported by pillars in the wall. Seven houses were built, spaced about 4.60 m apart, to let in the maximum amount of light, with the minimum amount of rain.

The spaces between the houses were planted with Russian comfrey, a plant that gives green food during the dry season. When firmly rooted, this plant is drought resistant and requires no watering throughout the dry season, although irrigation increases its yields. The plants are constantly fertilized during the dry season with a very fine dust from the sawdust and shavings litter, and during the rainy season they grow very rapidly. The litter is thought to react with the droppings to produce a fertilizer of high potash content, which Russian comfrey needs. Thus the birds grow their own green food.

Since the installation of this system, no illness has been recorded. No lice and worms have been found in any of the slaughtered birds. The obtained eggs have deep orange coloured yolks, in stead of the pale yolks common to Central Africa. The poultry houses are cleaned and the litter is turned weekly (10).

2.1.2 SAWDUST AS DAIRY BEDDING

Sawdust keeps cows cleaner than straw does, it is more efficient since it can be handled mechanically and less jamming of the liquid manure pumps occurs. Some farmers in Michigan use a mixture of sawdust and bark for dairy bedding. The ground bark helps to keep the sawdust better in place beneath the cattle. The problem is that not enough sawdust is available against reasonable costs (12).

A farmer in Malawi has developed a method to obtain a good fertilizer by using sawdust as litter in his cattle kraal. Fresh sawdust is spread on the earth floor to a depth of about 0.3 m. The initial dry sawdust should be watered to make it fairly damp. Each day the cattle droppings should be spread and fresh damp sawdust must be spread on top, to a depth of approx. 0.1 m. Even in the wet season the cattle lay down in the sawdust restfully. There are no flies, and there is no smell of ammonia losses. In contrast to the use of dry grass as litter (10).

The sawdust soon compacts with the weight of the cattle, so the whole mass has to be digged and turned over weekly. After 3 weeks the bedding litter is dug out and transported to the compost site, where it is piled in a heap, of approx. 4.5 m wide and 0.1 m deep. The litter is mixed with grass sods in a volume-rate of 1 box grass sods to 5 boxes of sawdust, spread to a depth of 0.3 m, and covered with green wilted weeds and vegetable refuse. This process is repeated until a height of 1.5 m is reached, after which the heap is covered with 0.1 m of turf soil, on which a good sprinkling of lime is spread. As soon as the heap is compacted, it should be turned over, or ploughed with a tractor, once, to allow the air in, while more lime can be spread over the top.

After 2,5 months the compost that is obtained is a good potting soil, and it can be used in a market garden to build up the soil structure. The 2,5 months old compost is not attacked by white ants, contrary to 4 months old compost, which is invaded by termites. So compost of 2,5 months old will allow the plants a good 6 weeks before the termites begin to rob the soil (10).

2.1.3 OTHER USES AS LITTER

Besides in poultry- and cow-houses, sawdust is also used as kennel bedding, in ridingschools, in meat, fish and vegetable markets and shops, in slaughterhouses and in meat packing industry. A small-scale application of sawdust is litter for

mice, guinea-pigs, rabbits etc. Other uses of sawdust are to
cover floors of taverns, garages, machine-shops, tanneries
etc. to absorb liquids (19,23,24,26).

In the last decades sawdust is more and more used as mulch.
Used in this way it retards erosion, hinders weed growing,
reduces water evaporation, insulates the soil against tempe-
rature changes, and keeps plants and fruits clean. Sawdust
mulch is used as such in orchards, around fruit-bearing
scrubs, strawberries, tomatoes, vegetables and flowers (3,6,
11,12,21).

Sawdust mulches are better than black polythylene film. When
spreaded approx. 25 mm deep they will more than double yields
of various vegetables (3).

Red sawdust is used for garden decoration (2).

2.2 SAWDUST AS FERTILIZER AND SOIL CONDITIONER

Sawdust, when well rotted, is a good fertilizer (16). As a source of plant nutrients, however sawdust cannot meet the requirements of micro-organisms, which break down cellulose and other high energy constituents. Table 2.1 shows the nutrient-content of some comportable matter (1 ton = 2000 lbs), table 2.2 shows the nitrogen and carbon percentage. It is clear that alfalfa is the most valuable material to compost (12). For softwoods the $N-P_2O_5-K_2O$ percentage is approximately 0.1-0.03-0.1 (3).

Table 2.1
Nutrients per ton of dry matter (12)

	N lbs	P_2O_5 lbs	K_2O lbs	CaO lbs	MgO lbs
Sawdust	4	2	4	6	0.5
Wheat straw	10	3	12	4	1.2
Alfalfa hay	48	10	28	28	7.0
Cow manure	12	7	12	7	3.0
Peat	20	2	1	28	10.0

Table 2.2
Nitrogen and carbon contents (12)

Material	N %	Cellul. %	Lignin %	C %	C:N
Alfalfa	2.34	29.8	14.2	43.2	18
Wheat straw	0.12	62.9	13.5	44.7	373
D.f. bark	0.20	42.2	41.6	58.6	293
D.f. wood	0.05	60.0	25.9	49.8	996

D.f. = douglas fir

The C-N ratio of green sawdust is very high: 500:1 or higher, depending on the kind of wood. Good compost is about 10:1 (3). Gardeners have to add a nitrogen fertilizer such as cottonseed meal, blood meal, etc. Many users did not apply a nitrogen supplement and were still satisfied with results, but the sawdust had to be well rotted (16).

When converted, however, sawdust will extract nitrogen. Green sawdust will give a temporarily noxious effect because of aerobic fermentation (6,19,11,12). The acids formed in this way can be neutralized through the addition of 0.25 kg of limestone per kg of sawdust, or its equivalent of ammonia (12).

Lignin is the only part of sawdust that has a good fertilizing quality. The carboxyl groups of this high-molecular aromatic compound have an ability to part with hydrogen and retain absorbed ions of ammonia, calcium, magnesium, potassium and other bases. In this way, lignin prevents soil nutrients from leaching, so that they are available to plants (25).
Thus, wood waste has a distinct advantage over most other agricultural wastes, because it continues to bind nitrogen for a longer time during decomposition, due to its lignin content (table 2.3) (3,6,10,12). The extent to which nitrogen can be bound or immobilized by several organic wastes is shown in table 2.4 (12).

Table 2.3
Nitrogen bound during
decomposition (12)

	10 d %	20 d %	40 d %	80 d %	160 d %
Softwoods	0.14	0.16	0.33	0.50	0.59
Hardwoods	0.78	1.10	1.21	1.17	1.10
Wheat straw	1.25	1.68	1.35	1.14	-

Table 2.4
Nitrogen immobilized
during decomposition (12)

Material	Incorp. lbs.N/ Ton D.M.	Mulch lbs.N/ Ton D.M.
Conifer sawdust	+15	+10
Hardwood sawdust	+25	+15
Hardwood chips	+10	+ 5
Cereal straws	+15 - +35	+10 - +20
Moss peat	+ 5 - +15	+ 5
Peat humus	- 2	- 0.1
Alfalfa hay	-25	-15

The high lignin content of wood produces more humus than most other organic materials. Humus is necessary for the crops (10,12), especially in the tropics where there is a great demand for humus (10).

Sawdust mixed thoroughly into the soil decomposes more rapidly and immobilizes nitrogen more intensely than when used as mulch and it also increases the permeability of the soil (12).

When using sawdust as soil conditioner mostly nitrogen (about 1.5%) and sometimes phosphate is added (3,6,11,12,21). Instead of 1.5% of nitrogen over 4.5% of ammonium nitrate (23-0-0), or over 3% of urea (45-0-0), or over 15% of a complete fertilizer (10-6-4), manure or greenery waste can be added (6,11,12). When used as mulch the nitrogen addition can be halved (12).

Research work in the U.S.A (U.S. Forestry Department and State Experiment Station) has shown, that the lignin part of the sawdust does not reduce soil nitrogen. The carbon content can be divided by 5.5 to get a workable C-N ratio (10). Especially in a compost pile, sawdust is an ideal material. It absorbs the excess moisture, keeps the pile porous and prevents compaction. It also provides structural strength (7). Composting gives a product that is low in readily decomposable components and higher in nitrogen (3).

Research workers in the Philippines found that untreated sawdust will give a good compost only after approx. eight months (1). However, sawdustcompost can be made within four months as follows:
a) soak sawdust (or other fine wood waste) during 24 hours;
b) make a pile of the wetted sawdust and compact it closely;
c) after 3 weeks the pile has to be dug up for aeration and covered with soil and hay.

The pile heats up and after three months a useful fertilizer has been obtained and can be spread on soil (11).
When several tons of sawdust are available, an "artificial" fertilizer can be produced by the addition of selected bacteria. The sawdust is transformed at temperatures up to 80° C through the activity of the bacteria. Analyses have shown that it has often a higher nitrogen content than ordinary manure (13).

Some compostmakers prefere specially cultivated inoculants, but usually they are not necessary, because they can easily be obtained from small applications of manure or of fertile soil (3).

2.2.1 SAWDUST COMPOST IN KENYA

In Kenya the following method of making a generally usable compost has been developed (10):

a) Fresh manure is put in a container by sprinkling a few drops of QR, (a (relatively cheap) bio-dynamic activator) on every 75 mm layer, and left to mature, covered with a lid to keep out rain;

b) After 24 hours two shovels full of matured manure are thoroughly mixed with water and put in a half 45-gallon (about 200 l) drum, split lengthwise. The drum is filled with more water and about 80 liter of sawdust is added to the slurry, until the mass becomes crumbly, after which it is thoroughly mixed with other agricultural wastes in a ratio of about 1:2 for fresh sawdust and 1:1 for slightly converted sawdust. In the same way the agricultural wastes have been mixed with manure slurry too;

c) The mixture is put in a bin with three walls: a wide fixed back, one movable side and the other side fixed (or the end of the previously built heap). See figure 2.2.
Each layer of about 150 mm is treated with QR. The open front should be built up as vertically as possible and the pile must be covered with polythene. The pile reaches a temperature of about 80°C and after 3 to 4 weeks a complete disintegration is obtained.

When the sawdust manure mass is mixed with 20% of matured compost, before putting it in the bin, a disintegration is obtained in 2 to 3 weeks. By using horse manure and sedge grass the obtained compost can be succesfully used for growing mushrooms (10).
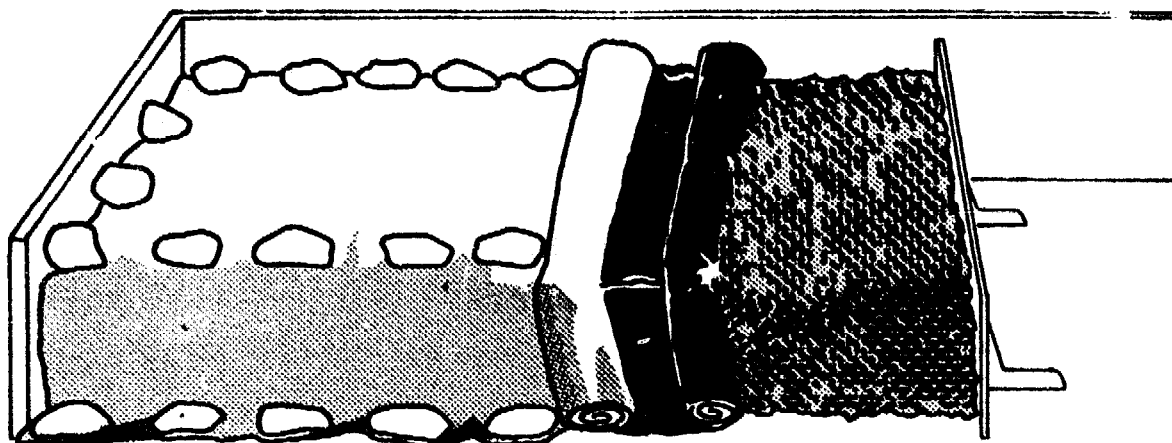
Figure 2.2 A compost bin

2.2.2 THE "WILDE" COMPOSTING SYSTEM

Wilde developed a combination of a chemical and a biological method. The sawdust is treated with anhydrous ammonia, neutralized with phosphonic acid and then inoculated with a cellulose-decomposing fungus: Coprinus ephemerus (25,3).

The inoculum is prepared in the following way:
50-gallon barrels are filled with fresh sawdust, which is treated with 1.36 kg of anhydrous ammonia per barrel, by way of 3 hollow, perforated aluminium probes, closed on one side. These probes are connected to an ammonia-containing cylinder by heavy rubber hoses. The operator should take precaution against inhaling ammonia fumes.

The treated sawdust is left for a week, after which it is spread on the floor and neutralized by sprinkling 15 l of a solution of phosphoric acid. This solution is prepared by pouring 130 ml of commercial 85% phosphoric acid into 15 l of water. Then 0.45 kg of 50% potassium, dissolved in about 7.5 l of water, if sprinkled on the sawdust. The material is thoroughly reworked and left on the ground. After a few days

about 3.5 1 of previously prepared inoculum is mixed into the treated material. It is desirable to add 7.5 1 of leaf mold or top soil as well. The mixture is put into the barrel again for composting and is kept moist by periodical watering. During this time the aluminium probes are used to aerate the mass, and is for that purpose connected to an air compressor. The mass attains temperatures of approx. 40°C. The whole sawdust is permeated with white fungal hyphae. Within a few weeks the appearance of ripening bodies of Coprinus Ephemerus will indicate the succes of the inoculation. The obtained compost can be used to inoculate other treated sawdust (25).

The total time needed to convert sawdust of most tree species of the temperate zone into a good compost is at least 4 weeks. An interesting detail is that the fungi are usually assisted in the decomposition by the larvae of Sciaridae or "fungus gnats". Figures 2.3 to 2.6 show the effect of the compost on the growth of respectively Monterey pine, corn, radishes, tabacco and tomatoes (25).
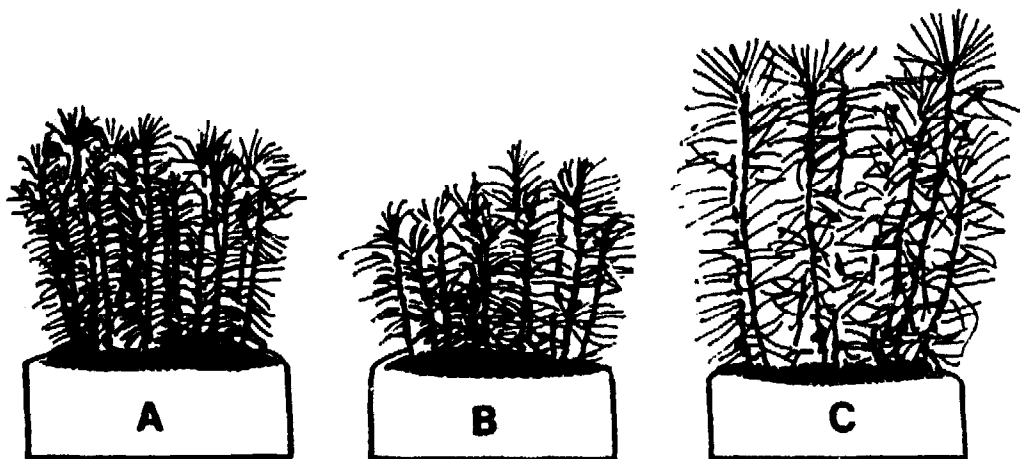
Figure 2.3
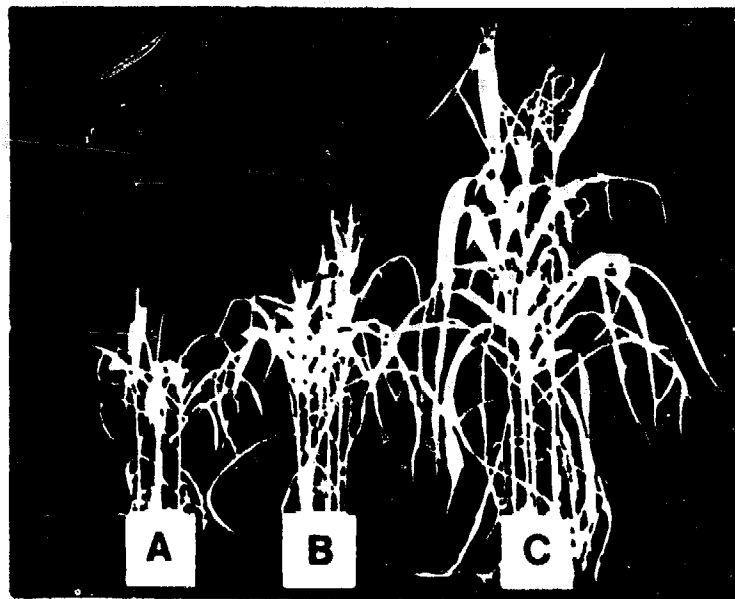
Figure 2.4
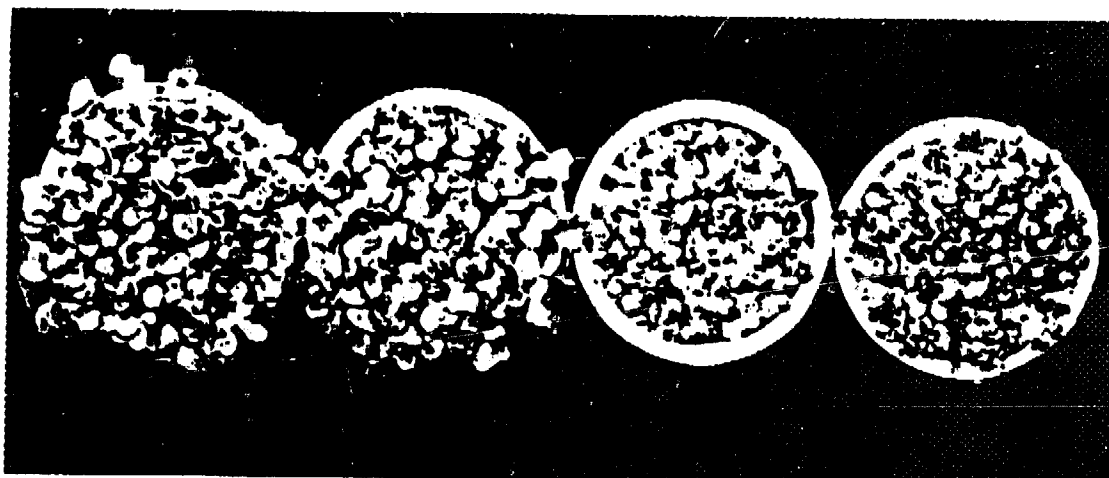
Effect of sawdust compost on the early development of radishes. Left: Plainfield outwash sand treated with 30 cubic yards of sawdust compost per acre. Right: similar untreated soil. Photograph taken four days after germination. Beneficial effect of compost became sharply pronounced 48 hours after germination.

Figure 2.5
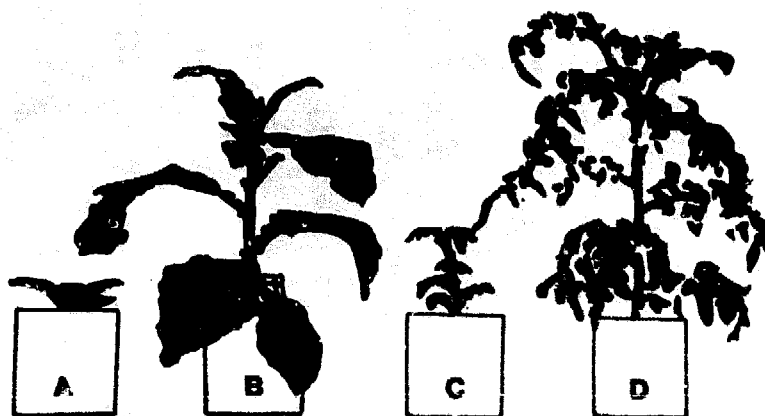
Figure 2.6

2.2.3 SAWDUST COMPOST WITH NUTRIENTS

Pretreating sawdust with small quantities of nutrients hastens decomposition with a carbon nitrogen ratio of 25:1 to 20:1 (1).

Treatment of sawdust with dilute sulfuric acid, at temperatures near the charring point, results in a decrease of hydrolyzable carbohydrates and an increase of non-hydrolyzable lignin. An addition of phosphoric acid increases the value of the sawdust fertilizer. The obtained product is less readily decomposable than the raw material. This reduces the microbial demand for nitrogen, when it is added to the soil. To neutralize the acid, ammonia is added. The fertilizer then contains enough nitrogen for its own decomposition (3).

The obtained compost contains about 3.3% nitrogen, 23.7% of this as nitrate and 47.5% as ammonium distillable at pH 7.4. About 30% of the nitrogen is organically bound, and relatively slowly available. When incubated with soil, this nitrogen is completely ammonified and nutrified within 30 days. The use of mineral fertilizer for nutrient fortification provides a more profitable product (3).

Combind Research Company at San Anselmo California developed a process for treating sawdust by pyrolysis. The pyrolysis converts readily decomposable constituents into more resistant forms, and it decreaes demand for nitrogen, when the product is applied to the soil (3).

Some beet and hop growers in Elgin (Or.) apply with good results a compost produced from sawdust mixed with feed pen manure. It analyzes a little bit better than 1-1-1 (N-P_2O_5 - K_2O.%) (3).

Research work at the University of Illinois has shown the effect of sawdust age and nitrogen application on the growth of Chrysanthemums. Sawdust was aged in piles on mill sites, and was exposed to natural climatic conditions during 5, 10 and 15 years. Before planting the potchrysanthemum cuttings, fresh sawdust and the three kinds of aged sawdust were each mixed with an equal volume of sand or mixed with equal volumes of soil and perlite, 1.8 kg/m^3 limestone and gypsum, and 0.6 kg/m^3 of superphosphate were added to the mixtures. As soon as the cuttings became established, the plants were irrigated with a 20-20-20 fertilizer solution at the rates of 100, 200, 300 and 400 ppm. Figures 2.7 and 2.8 show some results.

Figure 2.7 Effect of a 300 ppm fertilizer rate
on pot chrysantheums grown in different
ages of sawdust
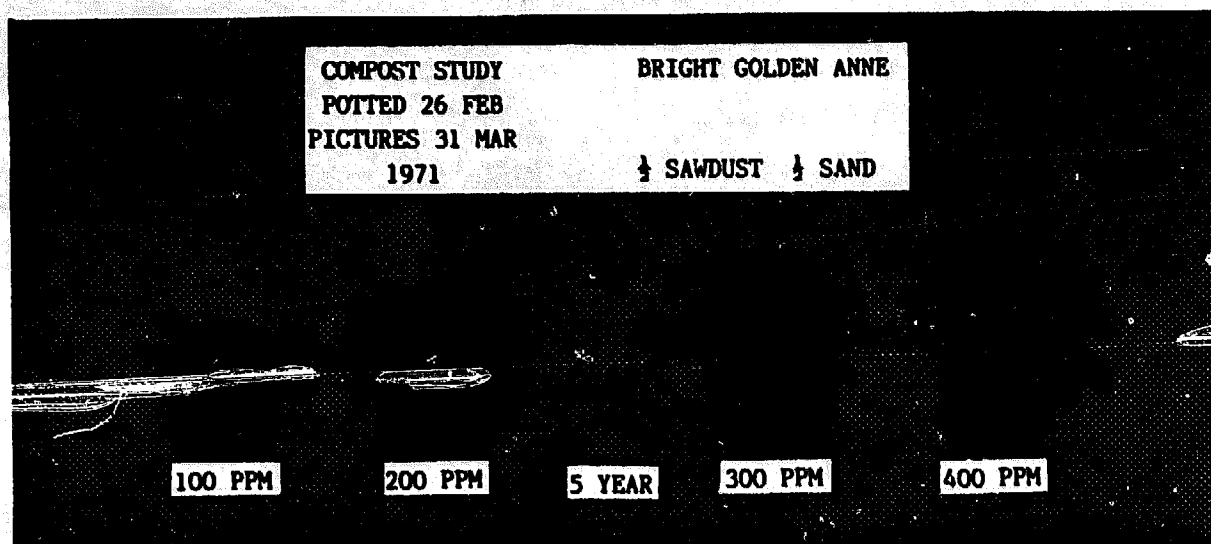
Figure 2.8

Mixtures containing 10 year or 15 year old sawdust give better results, while sawdust-sand media give greater yield than sawdust-soil-perlite mixtures, and an increased fertilizer rate increases plant growth in all ages of sawdust. A fertilizer rate of 100 ppm was too low. It has been found that the use of nitrogen may be the most important factor limiting the use of sawdust as an amendment in potting soils. Table 2.5 gives a summary of the test results.

Experiment II was the following test, which used only sawdust-sand (1:1) media and fertilizer rates from 200-500 ppm. The numbers in the table give the weights in pounds (1 pound = 0.4536 kg) of the plants cut off at ground level and dried in a forced draft oven at 55°C for 48 hours (20).

Table 2.5

	sawdust:sand 6 febr-17 may experiment I	sawdust:soil:perlite 6 febr-17 may experiment I	sawdust:sand 30 june-17 sept experiment II
	...........g. dry wt...........		
500 ppm 20 - 20 - 20			
15			42.8
10			40.8
5			28.5
fresh			32.3
400 ppm 20 - 20 - 20			
15	41.7	41.4	34.1
10	42.4	33.7	42.8
5	30.7	29.9	30.0
fresh	27.6	23.6	28.1
300 ppm 20 - 20 - 20			
15	35.9	35.4	40.1
10	39.4	38.3	44.3
5	28.6	22.8	25.9
fresh	21.7	23.6	21.8
200 ppm 20 - 20 - 20			
soil:peat:perlite	43.9	43.9	39.9
15	34.8	31.3	33.6
10	34.8	31.8	29.9
5	23.2	19.1	16.3
fresh	18.7	14.2	15.4
100 ppm 20 - 20 - 20			
15	15.7	13.3	
10	15.0	13.1	
5	11.1	9.2	
fresh	11.9	9.2	
lsd levels 5 %	3.73	3.73	4.89
1 %	5.00	5.00	6.39

Mean weight of 9 observations   3 cuttings per observation

2.2.4 COMPOST OF AGED SAWDUST

Research work at the West Virginia Agricultural Experiment Station has found that properly managed hardwood bark and sawdust mixes (1:1) can be used profitably as the basic constituents of a loamless compost for the growing of pot chrysanthemums and geraniums. The sawdust-bark mixture was aged in the open for 6 months. In the experiment calcium nitrate was added to one part of the mixture and ammonium nitrate to the other part. Three other media were tested too. Tables 2.6 and 2.7 show a summary of the total test results. The ammonium nitrate sawdust-bark blend gives the best results (18).

Table 2.6 Chrysanthemum (18)

Growth and flowering [1] of chrysanthemum morifolium 'radiance', pot mum, compared in five growing media, plants were potted five per pot and height measurements are from soil level to the highest point in the resulting plant mass.

Root number	Root media	Average height (cm)	Average number of flowers per pot	Number of pots
1	Bark:vermiculite	32.5 ab	18.3 a	16
2	Bark:sawd. + 9 oz. NH_4NO_3	34.7 b	23.0 b	16
3	Bark:sawd. + 10 oz.$Ca(NO_3)_2$	30.4 ac	13.4 ac	17
4	Peat:vermiculite	32.7 ac	12.1 c	15
5	Soil:sand:peat	29.1 c	13.9 c	16

[1] Numbers marked by the same subletter are not significantly different from each other according to Duncan's Multiple Range Test at 5 % level.

Table 2.7 Geranium (18)

Growth [1] of geranium pelargonium hortorum 'irene' compared in five types of compost. Measurements are of shoot growth.

Treatment number		Fresh weight (ozs.)	Number of leaves	Number of flowers	Number of buds
1	Bark:vermiculite	43 c	19 b	4.0 b	2.2 c
2	Bark:sawdust + NH_4NO_3	83 a	30 a	5.4 a	4.2 a
3	Bark:sawdust + $Ca(NO_3)_2$	38 c	20 b	5.2 a	2.6 b
4	Peat:vermiculite	90 a	19 b	5.8 a	3.4 ab
5	Soil:sand:peat	58 b	21 b	5.2 a	2.8 b

[1] Number marked by same subletter are not significantly different from each other according to Duncan's Multiple Range Test at the 5 % level.

Some market-gardeners plant their tomatoes, cucumbers etc. in plastic bags filled with closely packed sawdust only. Fertilizers are dissolved in water and added to the plants, mostly automatically, by irrigation of the sawdust. The advantages of this kind of growing are the general absence of disease-germs and weed seeds in the soil medium, its low weight and its comfort and cleanness.

2.2.5 OTHER USES OF SAWDUST FOR COMPOST

Currently, charcoal from sawdust is used as a potting medium especially in the cultivation of orchids. Charcoal improves the structure of the soil, particularly of heavy clay soils, and promotes the growth and vigor of plants, making possible wider applications for lawns, pastures, food crops, etc. (5). Effective insulation of the outer layer of sawdust, compacted under moist conditions, can cause charring by anaerobic fermentation. Sometimes spontaneous combustion results. The brown to black coloured sawdust becomes supersaturated with volatile acids and other fermentation products. It has a sharp, acid, and molasses-like smell and the fumes from a just opened pile are very irritating. When used as mulch or soil-conditioner plants may die, and shrubs may be affected. Over 25% of limestone is needed for neutralisation. Thoroughly leached with water or weathered for a year in a thin layer, however, it gives equal or better growth of cabbage, onions and tomatoes than fresh or aged sawdust (3).

The following sawdust blends are marketed in the U.S.A.: sawdust-manure; sawdust-peat-blacktop (1:1:1, an open soil mix suitable for potting base); soil-sawdust-loam-manure (3:4:1:2 and 4:4:1:2, low pH, open soil blends for flower boxes, indoor gardens or confined areas) and peat-sawdust-loam-manure (3:4:1:1), a potting blend) (2).

2.3 FEED FROM SAWDUST

Wood is a potential source of energy for ruminants, because itcontains 70-80% cellulose and hemicelluloses. However, in untreated wood the cellulose is virtually indigestible.
Methods to make the cellulose fit to eat must be inexpensive, because the market value must be somewhat below the costs of comparable feed commonly used (9,15).

When wood is steamed at elevated temperatures and pressures, the lignin plasticizes and parts of the hemicelluloses are converted into products soluble in water. In this way the carbonhydrates (derived mainly from the hemicelluloses) can be extracted with water. The wood molasses obtained through concentration can be used as liquid feed for cattle. When steaming hardwoods their digestibility for ruminant increases.
If aspen is steamed at 165-200°C it reaches the digestibility of hay (4).
Especially in wintertime hay is expensive, so aspen feed can be a profitable supplement of hay (14). It will be clear that sawdust (of aspen) can be used too, instead of chipped wood.

In Canada a method to use aspen chips or sawdust as feed for sheep and other ruminants has been developed. The wood waste must be steamed at a temperature of 160-170°C for 1.5 to 2 hours. The treated material has to be ground immediately, dried and stored in burlap bags until used. Since the treated wood contains insufficient nitrogen for the animals to maintain normal rumen function it is mixed with alfalfa hay (wood: hay = 60:40). To neutralize the acids formed during the steaming, ammonia can be added at the end of the process. The formed ammonium salts would be available as nitrogen source. The obtained feed is palatable and consumed readily by sheep. The feeding value of this feed was superior to alfalfa hay (harvested at full bloom) used as feed alone, based on both intake and digestibility.
Table 2.8 shows the digestibility and the digestible energy content (9).

Table 2.8 (9)

Digestibility and digestible energy content of alfalfa hay, steam treated wood, and a 60:40 wood:hay mixture.

	Digestion coefficients (%)		Gross energy (kcal/gm)	Digestible energy (kcal/gm)
	Dry matter	Energy		
Mixture	49.2 ± 0.49	46.4 ± 0.69	4.62	2.14 ± 0.029
Alfalfa hay [1]	50.6 ± 1.22	48.0 ± 0.47	4.39	2.11 ± 0.023
Steamed wood [2]	45.4 ± 0.78	45.4 ± 1.07	4.78	2.17 ± 0.049

[1] Previously determined.
[2] Digestibility by difference, digestible energy by direct calculation.

Steamed wood can be used in practical ruminant feeding systems in two ways:

a. As the roughage component of fattening rations in feedlot operations. This is probably the easiest use, because it is simple to refine the formula of such complete, mixed rations so as to provide the correct balance of nutrients.

b. As a part of an all roughage diet in feeding regimes that are designed for maintenance, or low level productions such as wintering of beef cows or sheep breeding flocks, levels of up to 70% wood to 30% hay are possible.

Especially when fed with grass hays, a little bit of protein supplement such as soybean meal and cottonseed cake could be added. Good quality alfalfa at 40% rate contains enough protein except in case of prolonged periods of feeding (9).

In the Institute of Wood Chemistry and Chemical Technology of Wood in Hamburg-Reinbek, chips of five kinds of hardwoods were steamed in a reaction vessel at a temperature of 187°C for 8 minutes and then desintegrated by a defibrator during 45 sec. After this the mass is washed with 10 parts of water for 1 part of dry fibre material, and with dilute alkali (0.5 to 1% NaOH). Table 2.9 gives the obtained percentages of

Table 2.9 Acid hydrolisates of water and NaOH extracts from wood and straw steamed at 187°C for 8 min. (4)

Species	Extract	Hydrolysis residue (% dry raw material)	Carbohydrates total % dry raw material	% total xylose	carbohy. glucose
Beech	H_2O	0.5	14	69	13
	(H_2O)-1% NaOH	5.7	7	83	3
Oak	H_2O	0.5	13	65	11
	(H_2O)-1% NaOH	4.0	7	81	5
Birch	H_2O	0.9	11	77	8
	(H_2O)-1% NaOH	5.4	7	84	3
	0.7% NaOH	5.9	17	80	5
Aspen	H_2O	0.5	8	76	6
	(H_2O)-1% NaOH	4.0	7	83	3
Eucalyptus	H_2O	0.3	10	71	8
	(H_2O)-1% NaOH	5.1	5	80	3

carbohydrates in the extracts and dry wood base, and the portion of xylose and glucose. The liquors can be concentrated to 60-65% solids and sold as liquid feed for cattle. Since digestibilities of the extracted fibre materials are too low, they cannot be accepted as feed (4).

A relatively cheap process to convert sawdust to a suitable feed for ruminants was developed by Holz-Institut Atlanta GmbH in Hamburg. The sawdust is soaked in 10% aqueous NaOH at room temperature. 70% of the total carbohydrates become digestible. Because of the simple and cheap equipment, this process could also be applied in developing countries (22).

In the Philippines experiments have been carried out using coconut trunk sawdust as cattle feed, untreated or prepared with nitric acid. It has been found that feeds containing sawdust give average daily gains larger than those with silage, although the feed efficiency values were much lower (8). The sawdust volume was determined with the use of screen sieve no. 6. The quantity of the sawdust is about 13.3% of the coconut trunk by gross volume when sawn into 25.4 mm - 127 mm lumber. Almost 80% of the sawdust was recovered for cattle feed (17).

In South Dakota material of the whole aspen tree was used as livestock feed. The chipped material was used in two ways: pelleted with alfalfa at a rate of 60:40, and ensilaged after mixing it with corn, limestone and urea in a ratio of 88.5:10.0:1.0:0.5.
Table 2.10 gives the chemical composition of the mixtures in comparison with that of hay.

Table 2.10   Chemical composition of rations (14)

Rations	Crude protein	Ether extract	Dry matter basis (%) Crude fiber	N free extract	Ash	Ca	P
Hay	6.05	2.50	31.46	51.65	8.34	0.47	0.16
Pellet	5.39	1.11	46.75	42.17	4.58	0.89	0.07
Silage*	3.11	0.61	49.82	43.08	3.38	0.54	0.06

* 1.2 kg soybean meat/head/day was added to increase crude protein content to approximately 7 %

The pellet ratio was so eagerly accepted by the animals that feed restrictions were necessary to eliminate chance of alfalfa bloat and to prevent excessive weight gain, which might cause calving difficulty. The animals refused the larger aspen chips in the silage feed. This feed should be supplemented with some protein (14).

2.4 CONCLUSION

In this chapter sawdust as litter and bedding, as fertilizer
and soil-conditioner and as feed have been described.
In general it may be concluded that many of the described uses
and technologies are appropriate for developing countries if
situational factors are favourable.

This applies especially for sawdust as litter and fertilizer,
as the required technologies are fairly cheap and easy to
manage. The production of cattle-feed from sawdust needs much
more capital investment. Besides, the research described was
carried out with the situation (both animals and trees) in
temperate zones in mind. Before specific recommendations for
tropical countries can te given, the local situation has to
be thoroughly analysed.

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3

SAWDUST IN BUILDING MATERIALS

ir g.j. arends

3. SAWDUST IN BUILDING MATERIALS

INTRODUCTION

Since wood is the most prevalent building material it will be obvious that people have also tried to use sawdust as a building material. And indeed many materials based on sawdust have been developed.

It is thought that because of economic reasons the use of sawdust as building materials should be preferred to its use as fuel or for chemical applications (11).

However, due to the dramatic increase of fuel-prices since 1973 and the high probability of further increases, it will be difficult to make a choice.

In this chapter an outline of the several products based on sawdust will be given. First the use of sawdust in its natural form will be treated (3.1). After that sawdust as raw material for stony materials (3.2) and board products (3.3) will be discussed. The final paragraph will deal with the use of finer sawdust and wood flour as raw material (3.4).

3.1 SAWDUST USED IN ITS NATURAL FORM

3.1.1 INSULATION MATERIAL

In the first decades of this century sawdust was mostly used as heat- and sound-insulating material. It was put between the outer and inner wall and between the ceilings and subfloors. In North America sawdust is spread on the ceilings of bungalows as a cheap insulator. Sawdust has a thermal conductivity of about 0,058 W/mK (25,30).
Sawdust prevents the formation of air-convection currents in the air space, thus reducing the heat conduction through the wall, and it stops the flow of draught through small cracks or openings in the wall. However, sawdust must be dry and remain dry. This can be attained by using a good grade of building paper or another, water proof, layer, or a treatment with waterglas (25,28). Sawdust will probably retard rather than stimulate the advance of flames (25,30). Sometimes however, it is impregnated with inflammable preservative (14). Formerly, sawdust was also used as an insulator for ice storage, especially where natural ice had to be stored (30).

3.1.2 REINFORCEMENT MATERIAL

A thick submerged layer of sawdust will provide a satisfactory foundation for muddy logging roads in bog areas (27).

3.1.3 CLIMATE CONTROL MATERIAL FOR FRESH CONCRETE

Another use of sawdust in its natural form is to spread a layer of 50 mm of moistened sawdust on concrete floors and roads, for a period of ten to fourteen days, keeping the concrete wet in order to enable it to obtain its greatest strength. Sawdust derived from some kinds of wood may impart a color to the finished floor (25,30).

3.2 SAWDUST IN STONY MATERIALS

3.2.1 SAWDUST IN BRICKS

Sawdust is used in bricks for insulation purposes. The clay is mixed with sawdust, pressed into forms and put in an oven. The sawdust burns out completely and porous bricks with considerable less weight (about 1150 kg/m^3) are obtained. The burning of the sawdust also creates more heat, resulting in the forming of clinkers (13,25,26). Aged, slightly decayed sawdust will give the best results (17). The bricks have a thermal conductivity of 0.41 W/mK.

The Scientific and Industrial Research Organisation (SIRO) in Australia has developed a building block made of a clay and sawdust blend. The blocks are provided with cams and grooves. To join the blocks without mortar, they must be manufactured with small variations in dimensions. They have a density of about two thirds of normal bricks. The 9 kg heavy blocks, with the same volume as 10 normal bricks, are especially suitable for self-builders (2).

3.2.2 SAWDUST IN MORTAR

The use of sawdust as an addition to mortar for stuccoing the fronts of houses found various applications in the first part of the 20th century. To plaster walls and ceilings a mortar composed of freshly slaked lime and softwood sawdust in as fibrous a condition as possible, was used. It was a very light mortar. In an extremely damp room where this plaster was used as wall coating, it showed no change in solidity or in appearance during 8 years. It was used to lighten the stucco or plaster mixture, and to secure firmer adhesion to the wall. Some proposed to use a mixture of equal parts of sawdust and plaster or cement. Others preferred slaked lime sawdust mixture with about 17% of plaster of Paris, 4.3% of glue and 1.7% of glycerin (13).

Sawdust in wall plaster prevents the formation of cracks and prevents the plaster from peeling off, something which is caused by water and ice on the side of the building most exposed to the weather.

A sawdust-cement-lime-sharp sand (2:1:2:3) mortar with dry and fine sawdust was used and coated with a cementcoat (13).

Two parts of sawdust (boiled for a long time in water glass, powdered asbestos and a little glue or other binding material to get an incombustible and non-hygroscopic mixture) plus one part of plaster of Paris or cement provide a stony mixture suited as a light building and insulation material of low porosity. The mixed material is poured with water into a mould. Hardening under pressure gives a very strong material. After hardening it is baked in a kiln or dried in a stove. This building material is used for the construction of walls and flooring, to make rooms damp-proof, as paving-stones, for building reservoirs and for vessels of every kind (13).

Sawdust is sometimes used in lime-kilns. The lime keeps its whiteness when it is heated with wood species (14).

3.2.3 WOOD CONCRETE

Sawdust is also added to concrete mortar to get a lightweight wood concrete: it is turned into (hollow) blocks and panels or used as a plaster. The cement-sawdust rate varies generally from 1:2 to 1:5, depending on its application. A ratio of 1:3 to 1:3.5 gives the best results. Some advantages of this material are its low density (about 500-1500 kg/m^3) and its better heat- and sound proofing qualities (the thermal conductivity varies from 0.66-1.01 W/mK). It is also easy to saw and to nail.

On the other hand there are some disadvantages too. The strength is scarcely 20% of that of normal concrete (crushing strengths of 4-14 N/mm^2 and transverse strenghts of 2.8-5.3 N/mm^2 after 28 days hardening) and shrinking and swelling rates are higher (0.2 to 0.55%). The values depend on the sawdust rate.

The disadvantages (but also the advantages!) decrease when sand is added. The compressive strength can be increased by adding materials such as lime or gypsum. The modulus of elasticity is about 2-2.5 KN/mm^2. Hardwood sawdust and some kinds of softwood species can interfere with the cement setting reaction, so they should be avoided. However, a treatment with a 5% solution of calcium chloride, hydrated lime, lime silk, or waterglass will nullify this bad effect. This will provide a good binding and also reduce swelling and shrinking (4,17, 23,28). A typical mixture is a cement-sawdust rate of 1:4 for insulation applications, a cement-sawdust-sand rate for blocks of 1:3:3 and a cement-sawdust-hydrated lime rate of 1:4:1 for plaster (24). In the USA wood concrete is used on floors of poultry houses, stables and livestock shelters (23). Sometimes it is reinforced with wire netting (13).

3.2.4 WOOD GRANITE

Wood granite or pressed wood is produced as a mixture of sawdust (about 30%) plus other fillers (such as asbestos, talc, corkmeal, marble and dolomite powder, etc.), various chemical ingredients, and a magnesite-magnesium chloride blend (MgO: $MgCl_2$ = 5:2). The MgO-$MgCl_2$ ratio is important: too much $MgCl_2$ will give a bad moisture resistance. The material is easy to saw, to drill and to nail. It can absorb impact and can be repaired by patching. The material is used for seamless subfloors, floortiles, slabs for covering floors, stairs, tables and counters, and even as door and window-frames. In India, the latter are about 40% cheaper than first-class timber, are termite free, and shutters can be attached with hinges and wood screws, in the same way as to any timber frame. However, they cannot be used in fully exposed situations and they require regular and careful painting. Wood-granite floors should be treated with wax or oil after 4 to 6 weeks of hardening (1,23,24,26,28).

3.3 SAWDUST IN BOARD PRODUCTS

The inclusion of wood residues in raw materials used for the production of board means great savings in the amount of standing timber used (9). In 1970 only 14% of the total wood residues in North America were used in the board manufacturing. Thus there was a potential for more extensive utilization of residues as raw material, if the basic economical problems of harvesting, transportation and supply of glue could be solved (19). Since wood materials for the panel industry have become scarce, possibilities to use a larger amount of wood residues -including sawdust- in the manufacturing of boards have been looked into (8,18). Though the manufacturing costs when using sawdust will be somewhat higher, sawdust itself is cheap, and in the future its use will therefore increase (9,10). However, the total quantity of sawdust will, depen- ding on situational factors, probably decrease as a result of improved saw log conversion processes (19).

There is also a tendency to develop and use saws which give coarser sawdust particles (18,30).
To get a product with a constant quality, large stocks of raw material have to be built up (29). The most important types of boards, consisting of finer wood particles, are particleboard and fiberboard.

3.3.1 PARTICLEBOARD

Particleboard is made from woodparticles bound with resin. The particles are derived from chipped roundwood, planer shavings, chips, sawdust and hogged material. It is applied in industry (such as furniture and shelving), in home construction (to underlay a floor for instance) and as decking in mobile home manufacture (19,24).
Figure 3.1 shows a schematic outline for particle board manufacture. The obtained raw wood particles are milled and screened to the desired size and dried with hot air
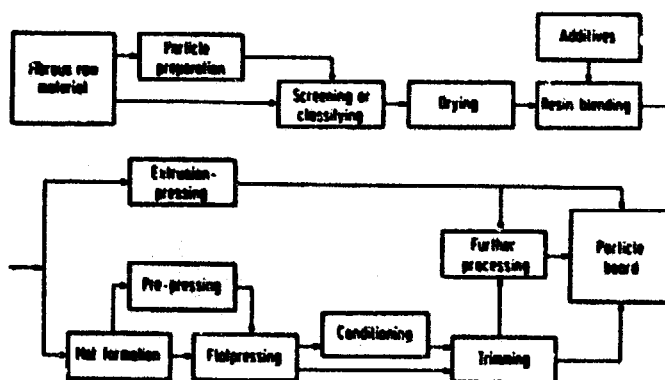
Figure 3.1 Schematic outline for particleboard
production (18)

exhaust-gases, or steam. Wooddust (including the finer part
of sawdust) can be used as fuel. After or during drying the
particles are separated by screening or sifting, usually by
means of air. Now the glue can be added in a batch operation
(the glue is sprayed onto the particle surfaces from above,
while the particles are in a tumbling movement) or in a conti-
nuous operation (the particles are glued by means of a cylin-
der or roller-gluing machine or a centrifugal-glue sprayer,
etc. by passing that installation in a continuous flow). The
particle glue-blend is spread in a consistently uniform slab
usually in one, single layer or in three layers (two face
layers and one core layer), either continuously or each board
separately. The slab can be prepressed. The uncut slab must be
sawn to boards before or after prepressing. The boards can be
weighed to control, after which they are put in a hot plate
press to be compressed to the desired thickness and density at
a temperature of 120-200°C and at a pressure of about 1.4 to
3.5 MPa. This takes about 4-10 min., depending on the raw
material and resin used, and on the desired mechanical proper-
ties. Especially the transverse tensile strength (IB) depends
highly on the curing time (18,24). Figure 3.2 and 3.3 (both
on the next page) show some schemes of particleboard plants.

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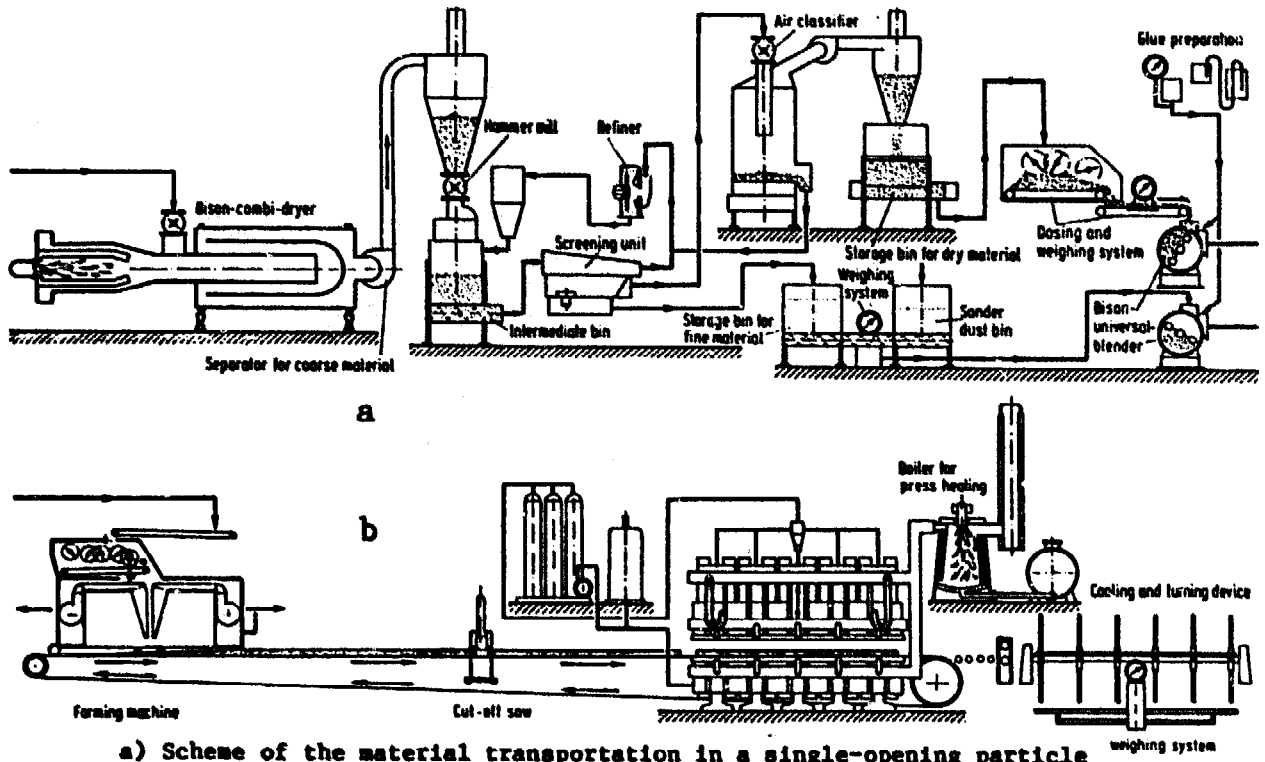
a) Scheme of the material transportation in a single-opening particle
   board plant

b) Scheme of single opening press operation

Figure 3.2 A single-opening particleboard plant (18)
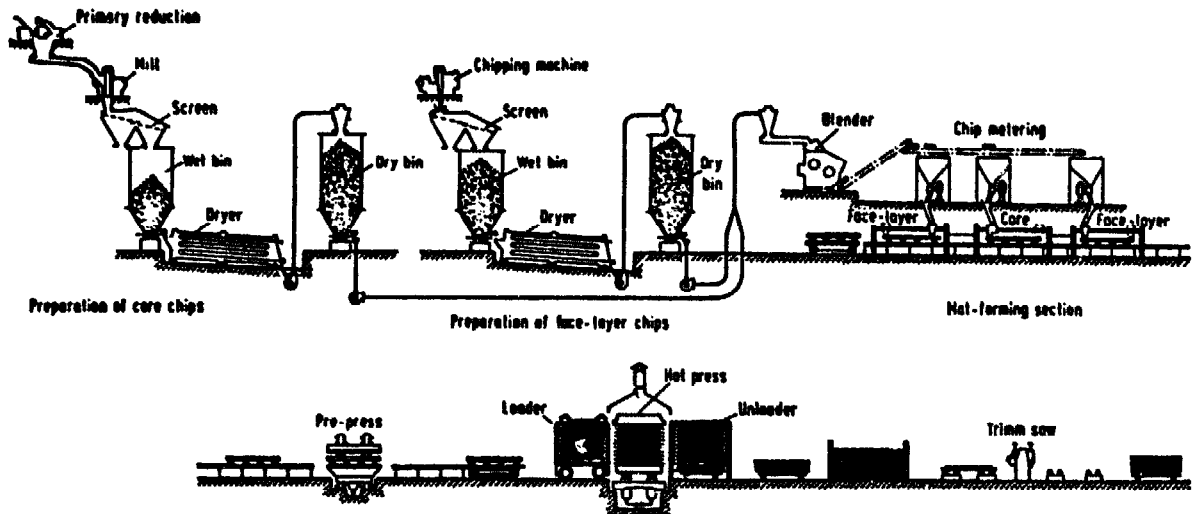
**Figure 3.3 Scheme of the manufacturing of a
three layer particleboard (18)**

Table 3.1 shows some normal average ranges of mechanical properties of board glued with urea-formaldehyde resin (18).

Table 3.1

	thick mm	density kg/m^3	MOR N/mm^2	E_b KN/mm^2	IB N/mm^2	TS N/mm^2	E_t KN/mm^2	NH$_t$ N	NH$_p$ N	S$_w$ %
minimum	4	400	12	1.2	0.3	3.4	1.0	24	12	6
max'mum	80	1200	30	4.4	0.8	3.4	3.7	36	18	10

(MOR = bending strength, E_b = bending modulus of elasticity, IB = transverse tensile strength, TS = tensile strength parallel to face, E_t = tensile modulus of elasticity, NH$_t$ and NH$_p$ = nail holding transverse and parallel to face, S$_w$ = swelling after 2 hours immersion in water)

The binders commonly used are urea-, phenol- and melamine-formaldehyde. Urea resin is the cheapest and most frequently used binder, melamine resin the less frequently used and the most expensive one. Phenolic resin needs higher pressing temperatures and longer pressing times, but gives better weather resistant boards for outside use (18).

3.3.1.1 PARTICLE BOARDS FROM SAWDUST

The first particleboards were made from sawdust, but the mechanical properties of those high-density one-layer boards were bad and the production was not profitable, since a lot of resin was needed. Coarse grained sawdust takes up too little glue but very fine particles absorb too much glue. Only an addition of less than 20% sawdust would not result in a change of its properties. Still, from sawdust low quality particleboards were produced (15,18).

Around 1965 the use of sawdust as raw material became interesting when the production of three layer boards with faces of fine particles began. Hardly a decade later sawdust was an important raw material, used in many particleboard plants. 10% of the used raw wood materials consists of sawdust; in Sweden even 45% (10,15,16,18,19).

In the USSR researchers developed a durable waterproof, fire-proof and fungus-resistant particleboard made with sawdust only. The undried sawdust was converted into boards (and other bonded articles) by using a mixture of a semi-finished product or the product resulting from the polycondensation and curing of a phenol- and urea-formaldehyde resin, and sulphonaphthenic acids, at temperatures of 60-70°C and at pressures of 0.3-0.5 MPa. By modifying the binder and adding porosity-producing agents, sawdust and unseasoned chips can be converted into an effective heat and sound insulator, easy to work with, nail into, screw on, and easy to glue and paint. Undried sawdust combined with 20 to 30% of a binding solution with a specific coefficient of adhesion gives a product whose dimensions do not change after being immersed in water for six months. These sawdust particleboards could be made cheaper than normal particleboard (23).

Using sawdust for the production of particleboard needs a spread compactness of about 120-180 kg/m^3. The sawdust particles must be screened out scrupulously and the thicker and coarser ones have to be reduced. During which one has to be careful not to raise dust, or to make the particles too small (15,16).

The bending strength (modulus of rupture, MOR) of a three layer board with a density of 680 kg/m^3, decreases with about 10% by using 25 to 50% sawdust in the face layers, and with about 20% by using 100% sawdust in the face layers (15).

Figure 3.4 shows the influence of the sawdust quota, in the
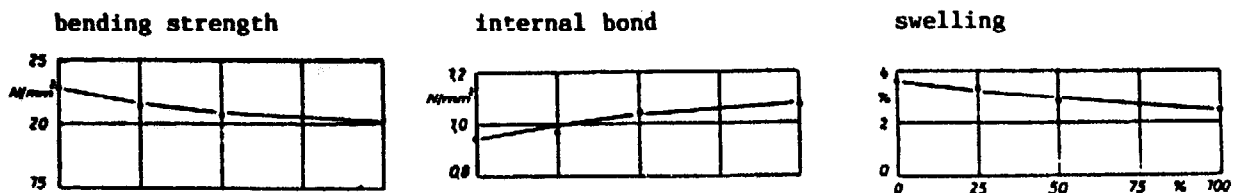
Figure 3.4 The influence of the sawdust quota in the core layer on the MOR, IB and swelling (16)

core layer on the bending strength (MOR), the tensile strength
perpendicular to face (internal bond, IB), and the thickness
gain (after laying in water for two hours). By raising the
sawdust content the bending strength improves, but swelling
decreases and the IB increases (16).

Another study did not clearly show a change of the mechani-
cal properties when the sawdust content in the core layer of
a three layer board was altered (table 3.2) (16).

Table 3.2   Properties of three layer particleboards at
             different (softwood) sawdust contents (16)

sawdust content %	0	15	30	50
density kg/m³	668	656	674	657
MOR N/mm²	21.3	21.0	21.1	21.2
IB N/mm²	0.58	0.55	0.61	0.63
swelling %	2.7	2.4	2.5	2.8

Sawdust is a "non-structural" particle type which somewhat
limits the use of particleboards produced with sawdust (10).

3.3.1.2 THE EXTRUSION PROCESS

After the second world war a method was developed in West-
Germany to produce particleboards in a progressive, continuous
and simple operation from hardly utilizable wood residues.
The so-called Okal extrusion process was one of the first
methods in the world for processing ordinary sawdust, produc-
ing boards of excellent compactness. Even vegetable waste
substances, in so far as they can be reduced to chips, can be
utilized. A relatively low percentage of resin is required:
sawdust used as raw material requires only 8% urea-formal-
dehyde, chips even as low as 5%. The procedure of the Okal
extrusion press method is shown in figure 3.5.

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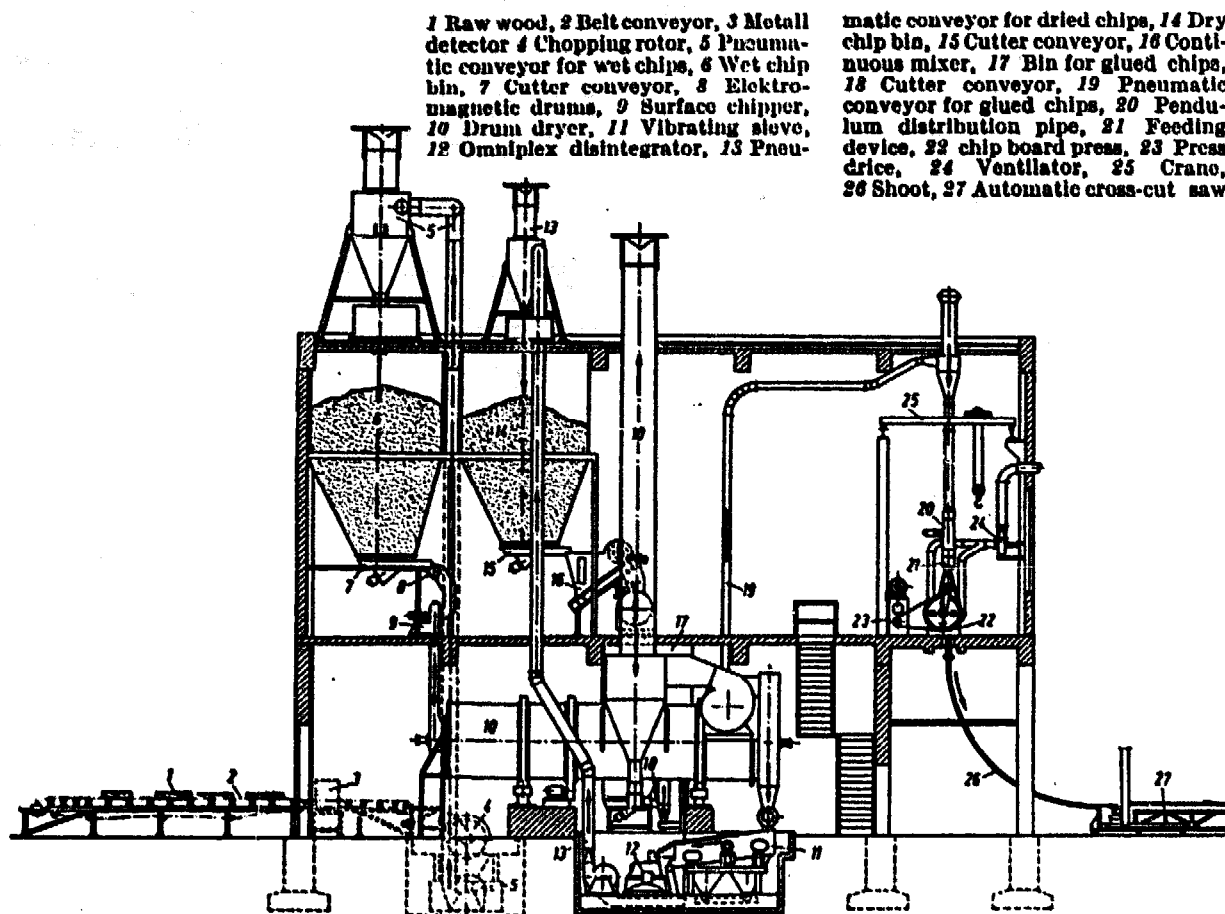
Figure 3.5   Scheme of a particleboard plant using the Okal extrusion process (18)

The purchase costs of the extruders are relatively low in respect to the productivity of the system. With the extrusion process boards of various shapes could be manufactured, for instance tubular boards. The extruded boards are used for several industrial and building applications such as interior decoration, furniture, table tops, wall board, etc. Tubular boards are used in manufaturing prefabricated houses. The extruded boards have a density of 580-620 kg/m^3, a transverse tensile strength (internal bound) of 1.5-1.7 N/mm^2 and a bending strength (MOR) of 8-10 N/mm^2 (18).

Other extrusion processes are the likewise vertical, chipcraft extrusion process and the horizontal Lanewood process (18).

3.3.1.3 LOW COST PARTICLEBOARDS IN INDIA

Because the resins generally used are very costly, in India the Regional Research Laboratory in Jammu Tawi has searched for alternative cheap binders, to produce cheaper particleboards. An example is Celex (sulphonated lignin, obtained as a by-product during sulphite cooking of woods). Pine bark posseses natural binding too, because of the presence of tannins and phenolic substances. Several sawdust-bark combinations and binder composites were tried. The composed material was dried and precured at 60-70°C, and then pressed at a temperature of 145-150°C, at a pressure of 2.5-3.5 MPa for 15 minutes. Most of the obtained boards had a low bending strength (2.5-6.5 N/mm^2) and great water absorption and swelling figures (some crumbled) after exposure to water. The boards with the highest bending strength (MOR) are given in table 3.3.

Table 3.3 Properties of some particleboards made, using different compositions (6)

material used	binder composition	density kg/m^3	MOR N/mm^2	water absorpt. 1 hr.	24 hr.	swelling % 1 hr.	24 hr.
fir sawdust 60% + pinebark 40%	3 % PF (ws)	1000	9.4	20	76	19	53
ditto 70% - 30%	4 % PF (ws)	1000	10.6	74	114	50	70
ditto 80% - 20%	5 % PF (ws)	1000	11.2	64	92	62	82
fir sawdust 95% + ricehusk 5%	6 % Celex + 4 % PF (ws)	1000	9.6	55	69	20	37
deodar sawd.80% + pinebark 20%	6 % Celex + 4 % PF (ws)	1000	15.2	7	14	13	24
ditto 70% - 30%	ditto 7%-3%	920	7.6	5	23	4	24
ditto 60% - 40%	ditto 8%-2%	1000	8.0	1	19	3	19
ditto 50% - 50%	ditto 9%-1%	940	8.0	11	26	12	36
ditto 50% - 50%	10 % Celex	940	8.1	14	x	13	x

Deodar sawdust-pine bark (80:20) with 7% Celex and 4% phenol formaldehyde (watersoluble) gives the best results (MOR = 15.2 N/mm^2). Fir sawdust-pine bark combinations with a phenol formaldehyde binder gives boards with a bending strength of 9.4-11.21 N/mm^2. A deodar sawdust-pine bark combination with a Celex-PF binder gives boards with a low water absorption and swelling rate. Made with Celex only, however, the board will crumble after a 24 hour exposure to water (6).

The Regional Research Laboratory in Jammu Tawi has tested some boards made of agricultural residues, of which large amounts are available in India. The resin-treated material was kept in a drying chamber at 70°C for about 45 minutes, as a precuring treatment and to adjust the moisture content. Table 3.4 gives the results of the boards made with sawdust.

Table 3.4   Properties of some composite boards from agro waste

no.	material	treatment	density	MOR	water absorption	swelling
1	FS + GNS (1:)	15 % PF	1080	19.4	20 (24 hr.)	13
2	FS + GNS + PH	10 % PF	1020	8.6	34 (24 hr.)	1,
3	FS + PH + IF	5 % PF	1000	10.0	10 (1 hr.)	7

FS = fir sawdust, IF = Ipomoea fibres (on one side), PF = groundnut shells, GNS = groundnut shells, PH = paddy husk.

The working conditions were: pressure = 3.5 MPa (1) and 7.0 MPa (2 and 3); temperature = 150°C; time = 15 minutes. The boards obtained had a thickness of about 10 mm. The properties are generally better then those found in previous research. Good boards are also obtained from combinations of paddy husk and sawdust with a surface of corn cob particles. A surface with resin impregnated glassfibre can give a more than 100% increase in strength (5).

3.3.2 FIBERBOARD

Fiberboards consist of ligno-cellulosic fibers with the felting of fibers and their inherent adhesive properties as a primary bond. Sometimes other bonding materials and/or additives are added. The fiberboards can roughly be divided into three types: soft (insulation board, density 350 kg/m^3), medium (half hardboard, density 350-800 kg/m^3) and hard (high density hardboard, density more than 800 kg/m^3) (18).
Insulation boards are used both in exterior construction applications (roof insulation, sheating, etc.) and in interior construction projects (building board, wallboard, plain or acoustical tiles, etc.). A fewer part is used industrially. Half hardboard is mainly used as exterior siding in building construction, while high-density hardboard is used in several applications in building construction and in industrial applications (furniture, etc.) (19). Fiberboards are made from fiberized wood chips, obtained from roundwood and manufacturing residues, including sawdust (18,19).
Green or wet particles can be defibrated more easily and with lower power consumption, so dry particles are wetted first. There are several ways to pulp the wood particles. The most frequently used processes are the Asplund or Defibrator method (a thermal-mechanical process) and the Masonite-process (the explosion method, commonly used in the USA) (18,24). Figure 3.6 shows a scheme of the Asplund- process.

3.3.2.1.a The Asplund-process

The Asplund-process is based on the utilization of lignocellulose raw materials. It is a continuous operation. The pulp produced consists mainly of fibers with the original fiber length preserved. The mechanical separation takes place at temperatures of about 160-190°C (depending on the type of the fibrous raw material) in a defibrator.
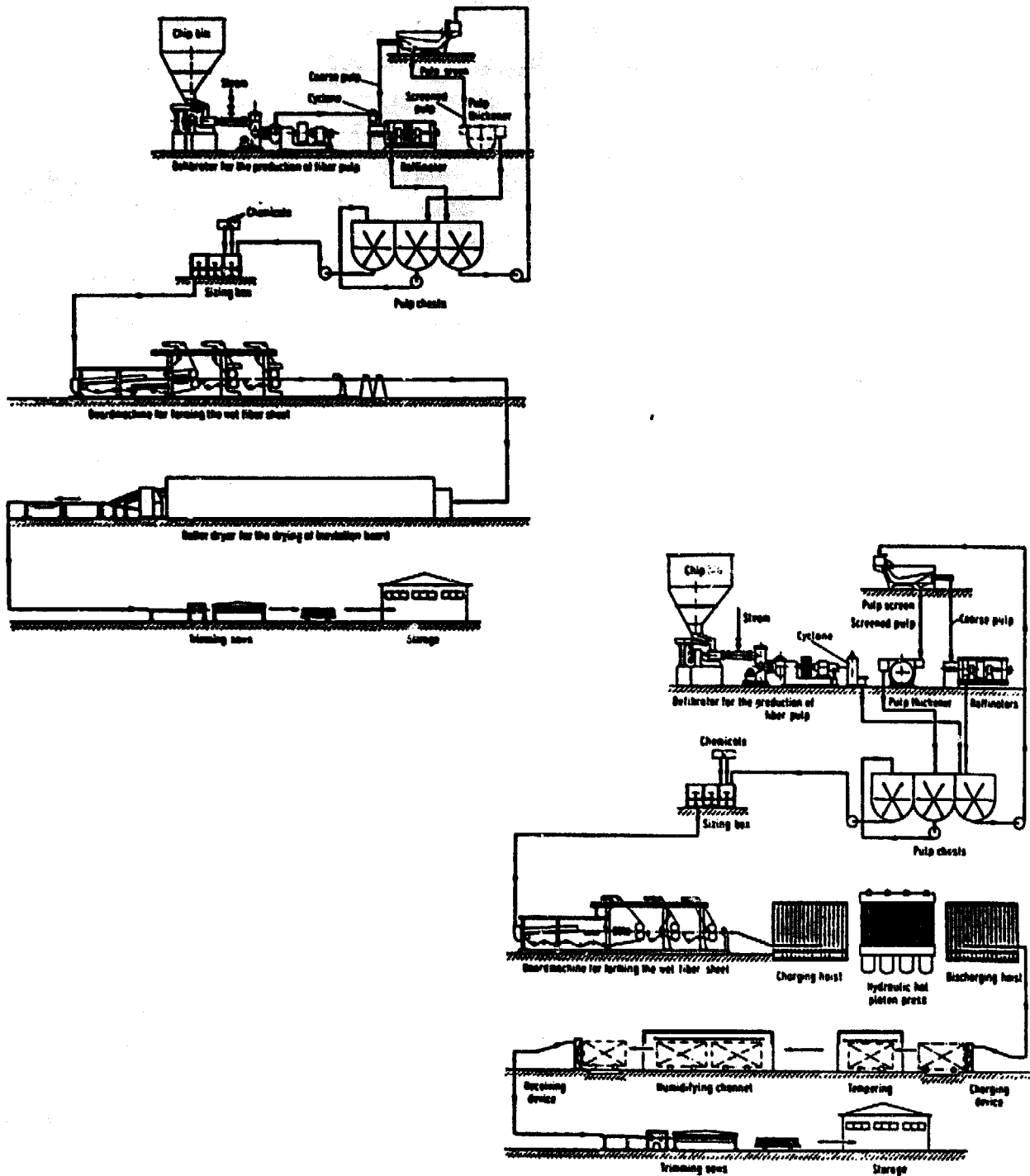
Figure 3.6 Scheme of the manufacture of insulation (top) and hardboard (bottom) using the Asplund-Defibrator process (18)

Higher temperatures must be avoided, because the hydrolysis of the wood hemicelluloses increases rapidly with a raise in temperature and so much material enters into the solution, that its strength will be much reduced. After about 1 minute the particles are ground between grooved rotating discs. The resulting strands of fibers are separated into discrete fibers during exposure of the slurry to atmospheric pressure (18,24). The Asplund-process has low conversion costs, due to low power and steam consumption. Fully automatic operation requires only one man for every two machines. The process gives a uniform highly loose pulp and has a high pulping yield (90-95%), while practically all kinds of ligno-cellulose raw materials can be processed (18).

3.3.2.1.b: The Masonite process

In the Masonite process the wood is pulped in a high pressure cylinder or fiber gun (figure 3.7). The gun is charged with
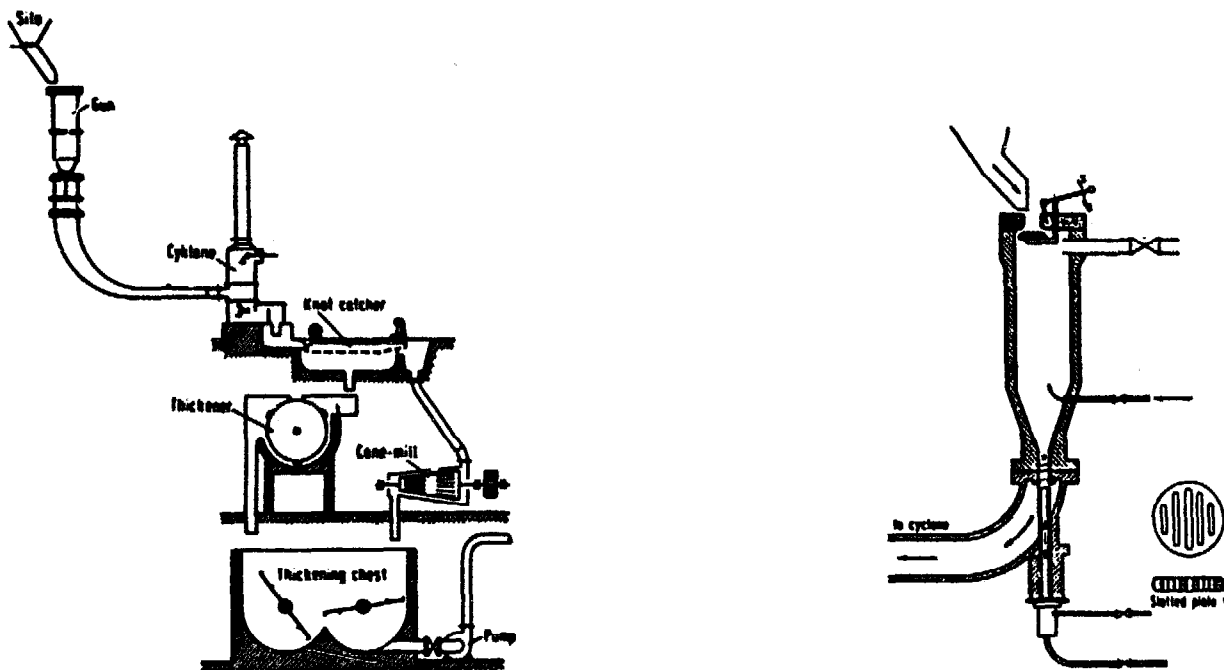
Figure 3.7 The Masonite-process with a
detail of the gun (18)

woodparticles, after which the charge valve is closed. Steam
is let in to raise the pressure till 2 to 4 MPa in about 30
sec. After about another 30 sec. the steam pressure is quickly
raised to 7 or 8 MPa (giving a temperature of 284 to 294°C),
and held at this level for about 5 sec, after which an exhaust
valve is quickly opened: "the gun is blown". The particles
pass through a slotted plate, and explode at once, due to the
high internal pressure, and a mass of brown fluffy long fiber
bundles is produced. The holding time at such high pressure is
very critical and depends on the properties of the particles
(18,24).

The gun fiber or fiber mass passes through a cyclone where
water is added and falls into a storage chest. Clear hot water
is led into the stock to wash out the sugars (formed by hydro-
lizing). Passing the cone mills the fibers are refined after
which they are screened to remove the fibers which are still
too coarse, these are processed once more.
The Masonite process is a discontinuous method, with a yield
of about 80%; one man can serve 6 to 7 guns, each with a yield
of 1500 to 2000 kg of dry fibers per hour (18).

3.3.2.2 FROM PULP TO BOARDS

The pulp formed in the pulping process is led in a board-
machine. There are three basic installations to form fiber
sheets:
a) **The deckle box**, consisting of a bottomless frame round a
   movable screen, on which the pulp is dropped and dewatered
   by a vacuum from below and by pressure applied from above,
   which also reduces the thickness of the sheet;
b) **The Fourdrinier-machine**, consisting of a conveyor screen,
   with suction boxes or a rubber suction belt under the wire
   to dewater the sheet;
c) **The cylinder-type machine**, consisting of a large sectioned
   drum filter (2.4-4.3 m in diameter) covered with a coarse
   wire and rotating in a vat that contains pulp; the sections
   in the pulp vat are subjected to vacuum in order to suck the

fibermass on the screen; the moment the sheet leaves the wire the vacuum is converted into a slight pressure, after which the sheet passes through a roll press for further water removing.

The first method is discontinuous. In the other methods the sheet must be cut into suitable lengths (18).

For insulation boards drying mostly takes place on continuous multideck roller-type dryers while drying agents (air and steam) circulate, this results in shorter drying periods.

It is simpler to load, needs less steam, gives a uniform drying over the whole working width and reduces the danger of staining. Heating is mostly done by air, heated either by steam (1.2-1.6 MPa) or by hot water (200°C). Figure 3.8 shows the scheme of a continuous roller dryer (18).
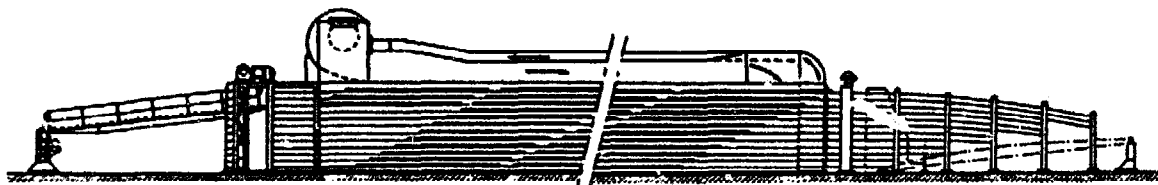
Figure 3.8   Scheme of a continuous roller dryer (18)

For wet pressed hardboards up to 1% paraffin wax emulsions or tall oil derivatives and/or phenol formaldehyde resins may be added. The latter increases strength and, to a lesser extent, somewhat water-resistance. The obtained sheets are put in a hot platen press, heated with steam or hot water. Hot water is the most efficient, the energy demand being about 10% lower. The boards are pressed at a temperature of about 200°C and a pressure up to 5 MPa for 8 minutes (18).

3.3.2.3   DRY AND SEMI-DRY PROCESSES

Besides the normally used wet processes, there are also semi-dry and dry processes. The sheets are formed by air felting,

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with which air suspension is used. The material used is
usually pulped in the same way as for wet processes. Dry or
nearly dry material is steamed and defibrated in disk mills,
in which the moisture added by steaming is partly removed by
friction heat. Moisture control is necessary. The felter unit
may be equipped with a suction box. Other devices are similar
to those used in wet processes. The semi-dry and dry processes
cause less pollution but the quality is inferior to that
obtained by wet felting. To improve its properties glue (1-4%)
is required. When fresh water is limited these dry methods
have advantages. Table 3.5 gives the main characteristics of

Table 3.5   Comparison of wet, semi-dry and dry fiberboard
            processes (18)

consumption per metric ton of product	wet process Scandinavia		semi-dry process U.S.A.	dry process Japan, U.S.A., France
	hardboard	insulat.b.		
raw water (m³)	10....25	10....20	10	7
steam (metric tons)	2.8..3.8	4.0..4.5	2.5..3.0	2.6..3.5
electric power (kWh)	380..450	550..650	500..600	500..600
yield (%)	65....82	90....95	85	85
waste water & pollution	greatest		less	least

the three processes. Dry and semi-dry processes also make
small plants feasible, with a production of 15 to 30 tons per
day, while wet processes would require 50 to 100 tons per day
in order to be profitable.
The cost of a dry-process plant is less than that of a wet-
process plant, but the cost of the resin makes the products
more expensive. Insulation board, however, can be made by wet
process only (18,24,27).

3.3.2.4   PROPERTIES OF FIBERBOARD

The average density, bending strength, bending modulus of
elasticity, tensile strength perpendecular to face (IB),
tensile strength parallel to face, screwholding (SH), water

absorbtion (WA) and swelling (SW) (after 24 hours immersion in water), the linear expansion (LE) (from 50% RH to 97% RH at 20°C) and the thermal conductivity (TC) are given in table 3.6 (18).

Table 3.6 Some properties of insulation and hardboard

	densitiy kg/m³	MOR N/mm²	EB KN/mm²	IB N/mm²	TS N/mm²	SH N	WA %	SW %	LE %	TC W/mK
insulation board										
- min	170	1	0.1	0.1	0.5	0	15	12	0.5	0.03
- max	400	5.4	0.9	0.2	3.4	850	100	20		0.07
hardboard										
- min	880	28	2.5	1.1	14	500	10		0.6	0.11
- max	1110	77	6.6	3.2	40	800	30			1.3

3.3.2.5 SAWDUST IN FIBERBOARD PRODUCTION

Formerly it was not possible to use sawdust as a high-grade raw material. Later only 10 to 30% could be added in hardboard production without noticeably changing the board properties. An analysis of typical sawdust particles derived from cutting coniferous wood with a gang saw is given in figure 3.9.
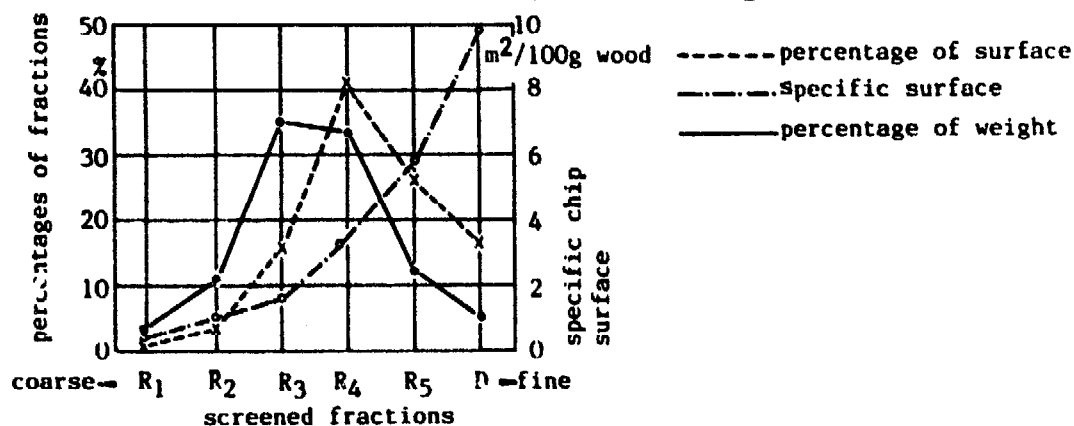
Figure 3.9 Analysis of gang saw sawdust from coniferous wood (18)

The main fractions R3 and R4 together make about 70% of the total weight, while their specific surface amounts about 15 to 33 m²/kg. Normally, used flakes have an average specific surface of about 15 m²/kg. The smaller the particles, the

larger the specific surface and therefore the more glue is
needed. The coarser sawdust can be pulped in the usual way.
Smaller particles and grinding dust from veneer plants are
suitable materials for face layers. Pulp from sawdust is very
suitable as face layer for hard, half-hard and insulation
board, in which case it must be refined in two or three stages
after the defibrator, depending on the desired board surface
(18).

Sawdust has become more and more important in the fiberboard
industry as well, due to the increasing scarcity of fiber raw
materials. Because of developments in machinery, processes
and material handling the use of sawdust up to 100% as raw
material for insulation and half hardboard is possible. In
North-America fiberboards are made almost exclusively on a
sawdust basis, while in Sweden medium hardboard is made of up
to 100% sawdust with a little glue added (15,18,19).

Oversized material must be screened out and be desintegrated
before being fed into the defibrators or alternatively it
could be fed into a chip based defibrator line. Silos, convey-
ors, chutes, funnels etc. have to be designed to suit the
special characteristics of sawdust to eliminate bridging and
other feeding troubles.

Sawdust screw feeders for defibrator preheaters must have
suitable compression ratios. The new types of screw feeders
can be used both for sawdust and ordinary chips. Older types
have to be adapted. The peripheral speed of the defibrator
and the number of bars in the disc have to be increased. The
precision and stability requirements of the defibrator have
become much greater (18).

3.3.3 MDF (Medium Density Fiberboards)

MDF is an intermediate form between fiberboard and particle
board. This type of board was developed because fiberboard
cannot be made thicker than about 12 mm. Otherwise the neces-
sary pressure time becomes too long, which is not conducive
to good quality hardboard.

Medium density fiberboard is produced with 7-9% urea resin

and 0.5 to 1% paraffin, as one- or three-layer boards. It has a density of over 500 kg/m^3, generally 700-800 kg/m^3. The MOR (bending strength) is 25 to 35 N/mm^2 and the modulus of elasticity about 3 kN/mm^2 (4). The board is mainly used in furniture manufacture (19). Since MDF is produced from fibers, it has a fine structure and is therefore easy to coat. MDF boards have a uniform density across its thickness and tight edges. This eliminates the uneconomical edge bending process used in conventional particleboard furniture core stock, and hinges can be screwed on the edges without any problems (4,7).

In the production of MDF, sawdust is a good raw material. Even bark and paper waste and other organic fibrous materials can be added up till 25%. The raw material is washed, so that iron particles, sand, etc. are removed, to save the installations and tools. After washing the material is transported under high pressure (by which the water is removed) into a preheater heated by steam of 150°C to 180°C. After 1 to 3 minutes the particles are dropped under steam pressure through an exhaust valve into a defibrator. The fibers are blown into a fiber-drier. During expansion under atmospheric pressure almost all of the condensed water will evaporate. The extremely small dimensions enable very quick drying. Resin can be added before or after drying. To add before drying prevents overglueing the fibers, which can cause glue spots on the boards. Moreover, it reduces the number of machines necessary.

In a mat-forming machine the fibers are dropped on a continuous screen conveyer, sucking the fibermat firmly onto the conveyor for compaction. The formed mat has a density of only 25-50 kg/m^3. In a prepress the thickness of the mat is reduced to about 25 to 50%. The edges are cut off and again returned to the process. The continuous mat is cut to length and conveyed to a hot press where it is pressed in the same conditions as particleboard, to obtain its ultimate form (4).

In the USA a MDF plant with a capacity of at least 160 m^3 per day can work profitably (28).

3.3.3.1 THE MILLER HOFFT PROCESS

Miller Hofft Inc. at Richmond Va. U.S.A., is the assignee of a process in which MDF-board is produced from wood particles such as sawdust with a 5% to 25% moisture content. If the particles are wetter they have to be dried untill this percentage is reached. After that the material is subjected to a steaming and mechanical reduction process to form a mass of lignocellulose material in fibrous form. A not yet active thermosetting resin is added to this mass. Then the mixture is compressed to the desired thickness between separately heated (above 90°C) platens, while a high frequency electric field of about 3-12 MHZ is created between the plates, long enough to initiate and at least partially complete the reaction of ingredients of the resin. The resin consists of urea and formaldehyde with or without melamine (3).

Table 3.7 gives a comparison of some properties of MDF-boards, with a thickness of 20 mm and a density of about

Table 3.7   Properties of MDS made by the Miller Hofft process from sawdust and chips varying in moisture content

raw material		chips		sawdust	
moisture content (wet basis)	%	30-60	5-25	30-60	5-25
modulus of rupture	N/mm²	30.2	31.6	21.1	21.8
modulus of elasticity	KN/mm²	2.64	2.67	2.25	2.25
internal bond	N/mm²	0.77	1.06	0.77	0.88
screw holding	N	1452	1520	998	1225
thickness swell [1]	%	5.5	4.0	4.5	3.0
water absorption [1]	%	19	13	14	8

[1] after 24 hours immersion in water

675 kg/m³ (oven dry), made of chips or sawdust with different moisture contents, treated with 8% resin and 1% wax. The press platen temperature was about 150°C with a high frequency heating time of 160 sec. (3).

3.3.3.2. MDF FOR INTERIOR USE

At the University of Illinois in Urbana-Champaign a study was carried out to evaluate the suitability of maple shavings including grinding dust, white oak chips, red oak sawdust, and four kinds of hardwood barks, as raw material for the manufacturing of dry-formed homogeneous, interior type, medium density fiberboard. Besides MDF, particle boards made from the same seven wood residues were tested too. For comparison purposes a fiberboard made of commercially prepared aspen fiber was obtained and tested (7).

The aspen wood material and half of each of the seven residues were defiberized in a commercial double-disk, steam pressurized attrition mill under conditions deemed best for each residue: the wood particles under a pressure of 0.7 MPa for 4 min. (maple and red oak) or 5 min. (white oak and aspen). The other part of the residues was processed through a hammer-mill with a 12.7 mm screen. 5, 7.5 or 10% of urea formaldehyde liquid resin and 1% wax emulsion was added and the obtained mixture was pressed during 9 min. at a temperature of 165°C to a thickness of about 16 mm and a density of 705 kg/m^3.

The test results indicate that the bark boards had good screwholding properties and internal bond but low bending strengths. The results of the boards made from the three kinds of wood particles are given in table 3.8. Most of the boards

Table 3.8 Properties of particleboards and MDF made from 2 kinds of hardwood residues and aspen fiber (8)

raw material	RC %	MOR N/mm^2		E$_b$ KN/mm^2		IB N/mm^2		TS N/mm^2		SH-face KN		LE %	
		Pb	MDF	Pb	MDF	Pb	MDF	Pb	MDF	Pb	MDF	Pb	MDF
maple	5	16.2	14.8	2.07	2.00	0.84	0.65	7.17	9.35	1.54	1.38	0.46	0.39
shav-	7.5	19.0	20.0	2.40	2.41	1.10	0.89	9.84	9.91	2.02	1.79	0.36	0.38
ings	10	21.1	22.9	2.66	2.76	1.20	1.17	10.55	10.83	2.27	1.91	0.32	0.43
white	5	9.8	17.9	1.45	1.83	1.30	0.46	4.92	7.73	1.72	1.13	0.43	0.35
oak	7.5	13.0	23.2	2.02	2.39	1.41	0.53	7.73	9.14	2.18	1.59	0.33	0.38
chips	10	14.1	23.9	2.04	2.49	2.05	0.53	9.42	12.66	2.27	1.81	0.37	0.40
aspen	5		16.2		2.33		0.42		10.48		0.92		0.24
fiber	7.5		20.0		2.40		0.49		11.04		1.00		0.21
	10		26.4		2.61		0.56		13.08		1.47		0.20

(RC = resin content, MOR = bending strength, E$_b$ = modulus of elasticity, IB = internal bond, TS = tensile strength, SH = screw holding, LE = linear expansion (50 to 90 % RH), Pb = particle board, MDF = medium density fiberboard)

have good properties. MDF gives better bending strength, stiffness and tensile strengths and tighter edges than the corresponding particleboards, but lower internal bond. All boards at 7.5 and 10% resin content and some of the 5% resin content exceed the minimum requirements for commercial type 1-B-1 particleboard of bending strength and stiffness. The internal bond of all boards, except the MDF with 5% resin made of white oak chips and the one made of commercial aspen fiber met the minimum requirements, while only the face screw holding property of MDF of aspen fiber with 5 and 7.5% resin content did not meet the requirements (see figure 3.10) (7).
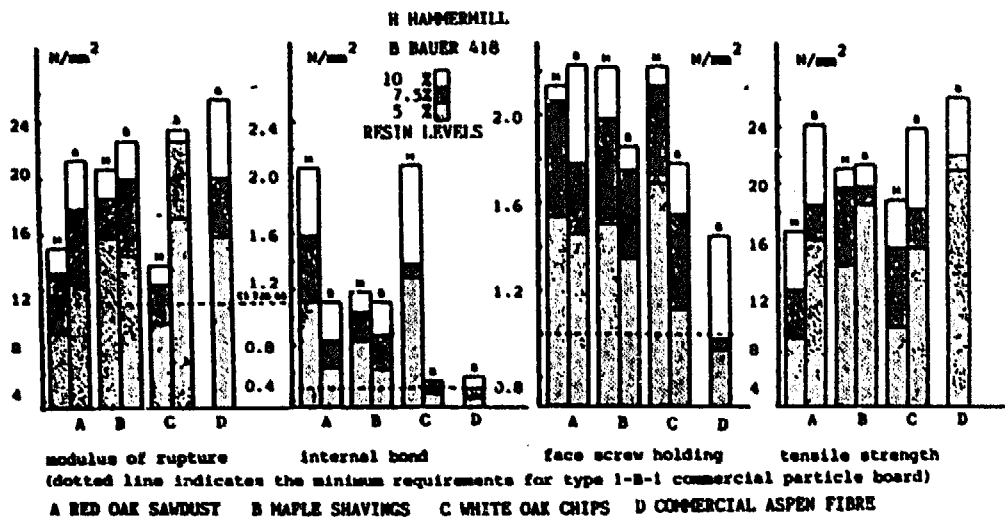
Figure 3.10   Effect of wood residue type,
              milling method and resin content
              on some mechanical properties (7)

3.3.3.3 MDF FOR EXTERIOR USE

At the same University of Illinois research laboratory MDF made of double-disc, steam pressure-refined red oak sawdust and/or bark with phenol-formaldehyde resin was tested as well. The sawdust bark was used in 4 ways: to make one layer boards of sawdust; of bark; of a sawdust-bark (1:1) blend; and three

layer boards with a bark core and sawdust faces (1:1) 4,5,6 or 9% of phenol-formaldehyde resin and 1% wax emulsion were added to the wood material (which had a moisture content of 8-10% before refining) and the whole was pressed for 9 min. at a temperature of 180°C to panels with a thickness of 12 mm and a nominal density of 700 kg/m^3, based on oven-dry weight and volume at the time of the test. All strength values were adjusted to this density, because these are linearly related to panel density. The boards made of sawdust and/or bark were manufactured in two ways: with or without treatment with a commercial grade of sodium pentachlorophenate, which was added to the phenolic resin and incorporated into the panel in a ratio based on the oven-dry weight of the wood and/or bark particles at a level of 1% (8).

The results showed that the sawdust boards were better than the bark boards. The latter generally did not meet the minimal requirements. The higher the resin content, the better the boards. The addition of sodium pentachlorophenate reduced the linear expansion and thickness swelling, but also reduced all of the strength and stiffness properties of the bark boards and almost all of the strength and stiffness properties of the sawdust boards. Table 3.9 gives the property values of the sawdust-boards, of the homogeneous and 3-layer sawdust-bark boards and the minimal US requirement for commercial exterior particleboard (the tensile strength according to the US standard for medium density hardboard). Calculated are the bendingstrength (MOR), modulus of elasti- city (E_b), internal bond (IB), tensile strength (TS, parallel to face), face screw-holding (SH-face), and thickness swelling (ThSw) and linear expansion (LE), both by a humidity changing from 50% to 90% R.H. All panels made from sawdust fibers, at 6.5 and 9% resin levels, meet or exceed the minimum average require- ments for strength and stiffness, but also exceed the maximum limit of the linear expansion. Excepting the tensile strength parallel to face, the same results were found with both kinds of sawdust-bark boards.

Table 3.9 Effect of phenolic resin content (RC) on average
properties of panels made from sawdust and sawdust
bark

Raw material	RC %	MOR N/mm^2	E_b kN/mm^2	IB N/mm^2	TS N/mm^2	SH-face KN	T_hS_w %	LE %
Red oak	4	12.7	2.43	0.35	5.2	1.14	4.8	0.51
sawdust	6.5	16.9	2.89	0.53	7.1	1.32	4.5	0.45
unpreserved	9	19.7	3.38	0.80	8.1	1.55	5.7	0.43
Sawdust + 1%	4	11.7	2.6	0.23	3.4	1.34	4.0	0.46
sodium penta-	6.5	13.9	2.83	0.56	6.7	1.36	3.5	0.41
chlorophenate	9	18.9	3.31	0.82	7.3	1.38	4.5	0.36
3-layer saw-	4	12.7	2.18	0.28	3.87	0.86	3.4	0.49
dust bark	6.5	16.2	2.61	0.46	4.93	1.23	3.2	0.48
(bark core)	9	16.9	2.71	0.6	5.63	1.32	3.0	0.56
Homogeneous	4	9.9	2.04	0.32	4.44	0.82	5.1	0.53
sawdust bark	6.5	12	2.47	0.49	5.28	1.14	3.8	0.51
board	9	13.4	2.5	0.67	6.00	1.27	3.0	0.63
Requirements for commercial board		12.7	1.76	0.46	7.0	1.02		0.35

Unpreserved red oak sawdust boards generally show the best
results. The three-layer boards have better bending strength,
stiffness, screwholding, thickness swelling and linear expan-
sion properties than homogeneous sawdust-bark boards, but the
latter have higher tensile strengths (both perpendicular (IB)
and parallel (TS) to face) (8).

3.4 USE OF FINER SAWDUST AND WOOD FLOUR

The fineness of the sawdust particles has an advantage when used as filler in composite materials (21). Products such as molded articles and linoleum require very fine sawdust or wood flour (25,28,30).

3.4.1 WOOD FLOUR PRODUCTION

Wood flour can be obtained by screening or sifting sawdust, but can also be made from coarser sawdust, shavings, etc. by crushing (in rollermills: rollers with steel teeth of varying degrees of fineness, working either in pairs that revolve in opposite directions, or on its own, moving on a stationary surface), impact fragmentation (hammer-mill), attrition (double and single attrition-mill, stone-mill) or cutting (rotary knife cutter, looks like a hammer-mill, but has "knives" instead of "swinging hammers"). The best known and most frequently used ones are the hammer-mill and the attrition-mill (figure 3.11) (25,30).
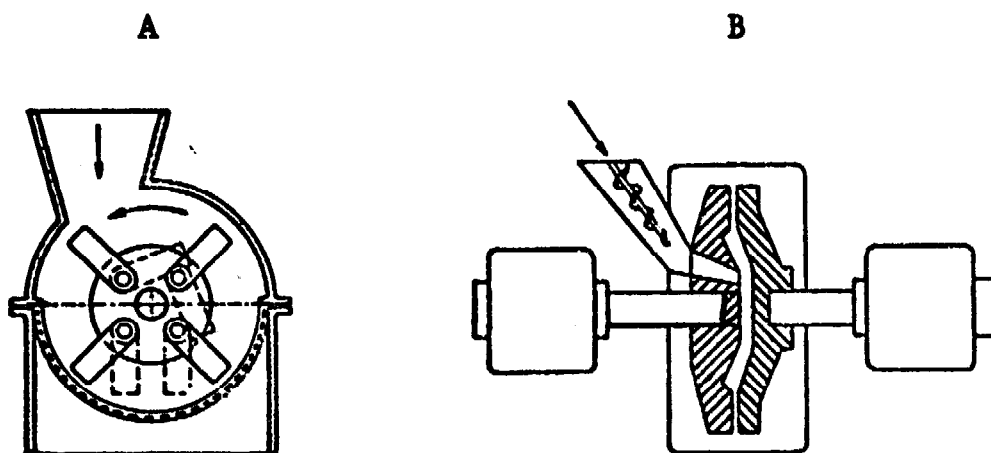
A   B

Figure 3.11 Scheme of a hammer-mill (A) and a Bauer double-disk attrition refiner (B) (18)

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A hammer-mill consists of free-swinging hammers, mounted on a rotating shaft. The wood particles are thrown against the casing of the machine and into the path of successive hammers. The fine particles drop through a screened opening (25).

A double disk attrition-mill or refiner consists of two corrugated metal disks covered with grinding plates of very hard steel, revolving in opposite directions. These are furnished with radial V-shaped depressions, whose edges produce sharp cutting surfaces. One of the disks is usually solid, while the other one is made of heavy steel spokes, so that the grinding plates on the latter do not extend to the center of the disk. The entire mechanism is enclosed in a stout iron case, and the material to be ground is fed through the spokes into the center of the machine. The particles are rubbed against the opposing plate and forced through the outer grinding rings and grow progressively smaller. The ground material is finally deposited on the bottom of the iron case and is drawn or blown off and carefully screened. A single attrition-mill consists of one spoked disk through which the machine is fed and an abrasive casing. The wood particles are ground between the disk and the casing, similar to that of the double disk refiner (25).

Especially in Northern-Europe many stone-mills are used. A common type consists of two large millstones, one of which is stationary and has a flat surface, while the other one revolves and has a somewhat concave surface with a sizeable opening in the center through which the wood particles are fed. The stones grind firmly against each other except near the center, due to the concave surface and the material is thus gradually reduced, and deposited as flour at the periphery of the stones (25,30).

The efficiency of any mill depends on the species of wood, its character (sawdust, shavings, etc) and the moisture

content of the raw material (25). The selection of the system should be determined by the above mentioned factors and by the desired fineness of the wood flour. Of course, an attrition-mill has lower maintenance and operating cost than a hammer-mill, and can deliver finer woodflour more effectively while superior wood flour, needed for some applications (where, for instance wood flour is required for highly polished surfaces) can be obtained as well. On the other hand, a hammer-mill has lower initial costs and usually presents a lower degree of fire hazard, due to the high air velocity and the extreme dense concentration of the flour within the mill. Sometimes the coarser wood particles are first put into a hammer-mill and after that into an attrition refiner, because the raw material feed in the latter must be finer (30).

Dark coloured species are not suited for light coloured plastics and linoleum; while a high resin content (deal or pine) or high acid content (oak) also limits its use (30).

3.4.2.1 MOLDED ARTICLES

Since the beginning of this century several methods enabling to use sawdust as a raw material for molded articles have been developed. It has found a great number of applications: backs for brushes, shoe heels, toys, dolls, picture frames, caddies, carcasses for (electric) equipment, wc seats, small boxes, phonograph records, letters for the printing press, chair bottoms and backs, slabs for covering tables, wall panels, mouldings, parquet floor slabs etc. Several resins such as phenol-formaldehyde, urea-formaldehyde, polyester and vinyl resin are used as binding materials and sometimes antiseptics, fire resisting materials, pigments and/or other fillers are added. Sometimes bone meal or blood is used as glue instead of synthetic resin. The whole is pressed under high pressure and temperature depending on the used raw material and the desired strength. The obtained product (artificial wood) has to be water-resistant, somewhat heat-resistant, easily to work with and not too brittle. Artificial wood as

replacement for normal wood must look as wood and must be easy to nail, saw, etc. (13,14,25,28).

Some older kinds of artificial wood are wood marble (ivory waste, woodflour and other waste materials, mixed with pigments, water-glass and glue), Latry (fine sawdust and blood albumin), "Simili bois" (woodflour-calcium phosphate-resinous or gelatinous material (1:1:1) blend), Sciffarin (wood flour, gelatinous mass, minerals and starch), and bakelite (synthetic resin with wood flour as filler, developed by dr. Baekeland who was the first to develop the synthetic resin in a commercial product) (13,25,28).

Some manufacturers of molded articles are the Scierie Pasteur at Pontarlier (Fr) and the Holzwerke factory at Zapfendorf (FRG). Generally molded articles are very expensive (14).
Sawdust mixed with urea-formaldehyde and a blend of the monomers styrene and maleic acid anhydride will give a dense and very strong molded article when pressed at a temperature of 150°C and 15 to 24 MPa. The obtained product has a density of 1400 kg/m^3, it hardly absorbs water, is weather resistant and has a good heat resistance (up to 225°C) (29).

When treated with phosphoric acid fine woodwaste particles give excellent moldable materials, without the need of an added binder. Table 3.10 shows the density, bending strength (MOR), straight nail (NH) and screw (SH) pull, and the weight (WG) and thicknes (TG) gain after 9 days soaking in water,

Table 3.10 Properties of some molded fine wood particles
compared with particleboard (21)

Raw material	density kg/m^3	MOR N/mm^2	NH N	SH N	WG %	TG %
pine	1060	16.2	177	1143	23	12
alder	1030	15.1	-	-	39	21
redwood	1110	22.8	-	-	54	11
particleboard	880	10.6	254	1252	64	22

compared with particle board. The fine wood particles were molded to boards with a thickness of 7.6 mm at a temperature of 150°C and a pressure of 3.5 MPa for 3 (pine and redwood) or 5 (alder) minutes (21).

3.4.2.2 PLASTIC WOOD

Plastic wood, used to repair wood blemishes, is made from the wood flour of the desired wood, volatile binders (such as cellulose ether, acetone, xylene or petrol) and some fillers. After hardening plastic wood is water- and heat resistant and can be worked in the same manner as normal wood (28).

3.4.2.3 LINOLEUM

Linoleum is made of canvas or burlap coated by means of oxidized linseed oil and resins with ground cork or kaurigum, wood flour and pigments. The whole is led between two huge heated rollers to press it to a solid tough floor cloth (24,25,28).
The coating of the canvas can take place on two ways. In the manufacture of "straight line inlays" the wood flour, resin, linseed oil, etc. is mixed and the resulting mass is rolled into layers, cut into the desired figures and glued to the burlap backing by the rollers. In the manufacture of "granular inlays" the mixture is kept in a granulated condition, which will compact under the application of pressure. Each of the several colours constituting the finished pattern is sifted down onto the burlap backing by means of a thin metal stencil. After one figure and colour is applied the burlap is pulled slowly forward on the two rollers (25).

3.4.2.4 WALL PAPER

Wood flour is also used to a limited extend in the manufacture of oatmeal wall paper in a quite fibrous condition. The tiny fibers give a subdued or silver tone to the darker base

colour of the paper. The wood flour is pulped and mixed with the paper stock forming the base of the sheet of paper. Since the minute woodfibers have not been allowed to become hydrated or saturated with water, they have a tendency to float and thus appear on the surface of the sheet of paper, which gives the "oatmeal" effect (25).

3.5 CONCLUSION

Many sawdust applications in building industry are well known and have proved their viability.

Some of the techniques to use sawdust in the building industry are cheap and easy to handle, especially when the sawdust is used in its natural form or in stony materials.
However, the unavoidable transportation cost reduces the attractiveness of these uses.
Application of sawdust in board products is a complicated process and will be economically viable only when large amounts of sawdust are regularly available.
Again, knowledge of the specific local conditions is necessary before decisions can be made about the appropriateness of the described techniques.

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4

SAWDUST IN CHEMICAL INDUSTRIES

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4.1 CHEMICAL DESCRIPTION OF SAWDUST

4.1.1 INTRODUCTION

Sawdust, which is a waste product of the lumber industry and other wood-processing industries, is available in large quantities in most, developed as well as developing, countries of the world. In this chapter the possibilities to use sawdust as a raw material for chemical industries will be discussed.
The utilization of sawdust presents considerable difficulty, especially damp sawdust is an awkward material to handle. The method of utilization must be sufficiently profitable to cover the cost of collection, transport and storage (1). Some of the processes for the chemical utilization of wood have been devised specifically with the object of finding a useful outlet for part of the very large quantities of waste wood. Chemists have devoted a great deal of effort to the study of methods by which the organic matter of wood may be converted into useful products. However, the main chemical industries based on wood (pulping processes) operate on a large scale and require for their efficient working a large, continuous and uniform supply of good quality raw material. They have not been considered to provide a solution to the problem of the utilization of waste and inferior wood, though in some cases they are able to absorb a proportion of material of this kind. Recent developments have shown that sawdust can be used for the production of woodpulp (see section 4.4). Another process which has been proposed more specifically for the utilization of waste wood is hydrolysis (see section 4.2). Furthermore a number of relatively small-scale uses also exist for sawdust, but in many of these dry sawdust is required (1,2).
The conversion of the organic matter in sawdust into useful products will be examined in the following sections. In this section we will discuss the classification of wood, the chemical composition and structure of sawdust and methods of separation and fractionation and uses of sawdust components.

4.1.2 THE CLASSIFICATION OF WOOD

Botanically wood can be classified into two categories, namely hardwood (deciduous wood) and softwood (coniferous or evergreen wood). They contain different amounts of their main constituents: cellulose, hemicellulose and lignin.

Table 4.1 Average percent chemical composition of softwoods and hardwoods (4)

	softwoods	hardwoods
cellulose	42 + 2	45 + 2
hemicellulose	27 + 2	30 + 5
lignin	28 + 3	20 + 4
extractives	3 + 2	5 + 3

Some of the important species of hardwood are aspen, white ash, birch, beech, black and red gum, elm, maple and sycamore. This class of wood is generally hard to work, whereas softwoods are very easy to work but not as durable as hardwood. This class of softwood includes spruce, fir pine and cypress. These species are well known for their long fibre lengths and therefore they are mostly used for the production of good quality pulp for papermaking and for rayon and other products where fibre length is an advantage. With special reference to Kenya (3) we note that among the country's well known indigenous hardwoods are East-African camphorwood and muhuhu. The latter is used for woodcarvings and flooring blocks. The only indigenous softwoods are podo and pencil cedar. Cypress and pine have been introduced because the availability of podo is limited. The timber of pine and cypres are also more suitable for many of the purposes for which podo is used at present.

4.1.3 CHEMICAl COMPOSITION OF WOOD

Wood mainly consists of hemicellulose, cellulose and lignin. The name lignocellulose is used to describe all mixtures of these constituents, including agricultural waste and wood waste. Apart from these main components, wood contains small amounts of other organic matter: resins, tannins and essential oils, depending upon the species of wood. Tannin is mostly contained in the bark of the tree. In table 4.2 the analysis of eight species of Canadian wood is given.

Table 4.2

Component[1]	*Bf	Ws	Bs	Jp	Eh	Wp	Wb	Ap
Alcohol bezene	4.25	3.06	2.55	6.54	2.18	9.77	4.88	3.82
Hot water extr.[2]	0.39	0.69	0.75	1.83	1.69	1.16	0.69	0.82
Ash	0.40	0.22	0.21	0.19	0.28	0.18	0.29	0.38
Acetyl	1.52	1.08	1.14	1.08	1.32	1.15	4.94	3.41
Lignin	27.70	26.96	27.25	27.38	29.56	25.60	18.48	18.12
a-Cellulose	49.41	50.24	51.10	47.52	53.04	48.10	40.97	49.43
Hemicelluloses	15.41	16.39	15.18	16.18	12.51	14.13	27.25	21.18
Total	99.08	98.64	98.18	100.72	100.58	100.09	97.10	97.16

*Bf = Balsam fir, Ws = White spruce, Bs = Black spruce, Jc = Jack pine, Eh = Eastern hemlock, Wh = White pine, Wb = White birch, Ap = Aspen poplar

[1]All values in percent
[2]Hot water extraction on residue from alcohol-benzene extraction

The major component of wood is cellulose, which is a linear polysaccharide (hexosan). It is distinguished from most of the other polysaccharides in that it yields only D-glucose upon hydrolysis (see figure 4.1a). Cellulose exists both in amorphous and in crystalline form, the latter is more difficult to hydrolyse. The hemicellulose fraction contains all the noncellulosic polysaccharides and related substances. Hemicellulose is a heteropolymer composed of various pentoses and hexoses (see figure 4.1b). Upon hydrolysis it yields xylose, arabinose and small amounts of hexoses and some sugar acids.
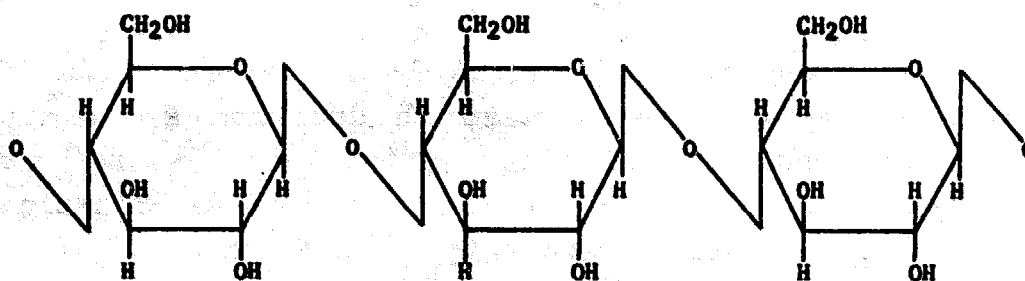
Figure 4.1a Cellulose

Figure 4.1b Hemicellulose
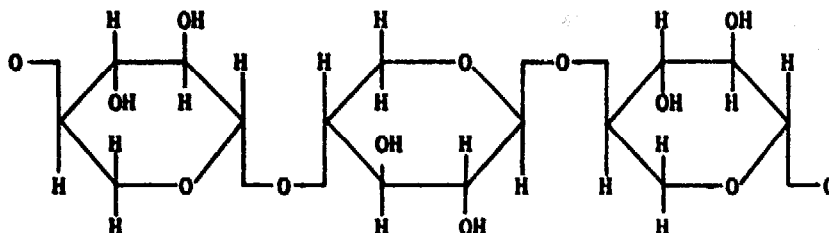
From softwoods, the yield of hexoses is higher than from hard-
woods. Lignin is an amorphous substance which has a three
dimensional polymeric structure containing single-ring
aromatic structures (see figure 4.2). Lignin consists of
phenylpropane units and is responsible for the rigidity of
plants. It is highly resistant to chemical and enzymatic
attack.
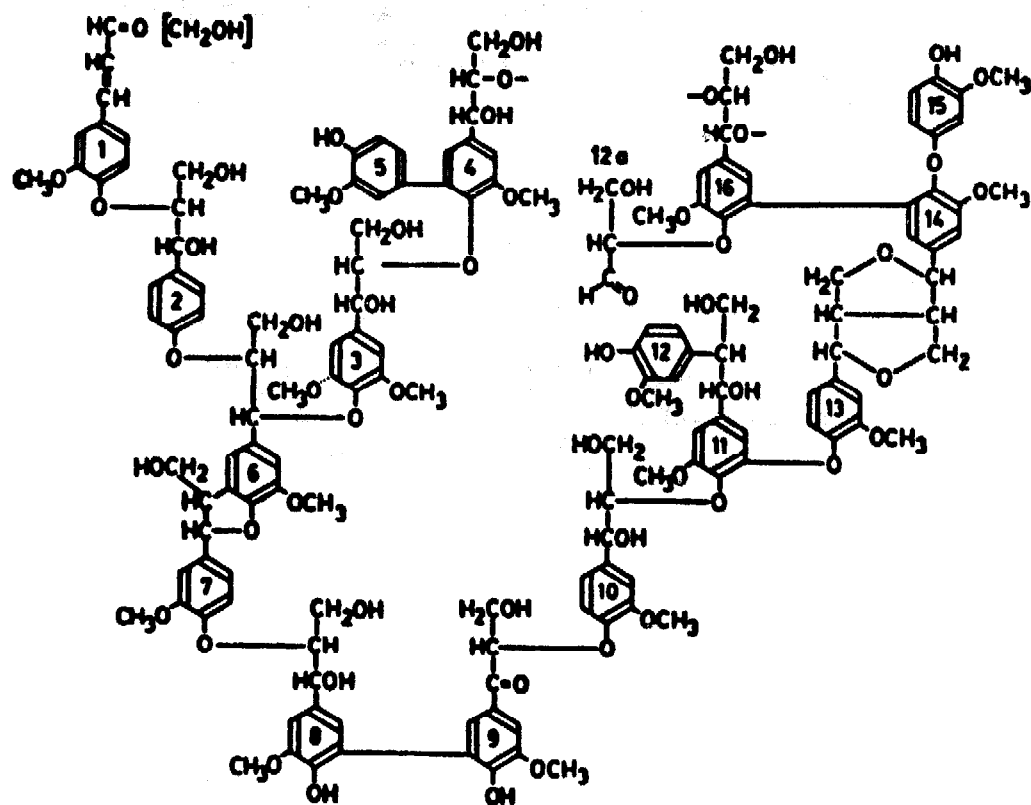
Figure 4.2   The structure of lignin

4.1.4 POSSIBLE USES OF WOOD CONSTITUENTS IN THE CHEMICAL INDUSTRY

The relative proportions of the three major components of wood change by the species. Due to the different structures of wood components and the way they are stored in plants the hydrolysis of lignocellulosic material is a complex phenomenon, though the chemical reaction itself is quite simple. Upon hydrolysis wood produces a mixture of sugars and various by-products. However, the success of the utilization of lignocellulosic material, such as sawdust, depends upon the efficient use of all the components. One way to achieve this aim is to separate the material into its primary constituents and subsequently to convert these into the desired chemicals using different conversion processes (see figure 4.3). For example the conversion

Figure 4.3 Chemical products derived from lignocellulosic material

of cellulose to glucose can be the forerunner of many applications in the food industry, fermentation technology and fuel production. Glucose may be used as a starting material leading to many fermentation products made at present: organic acids, vitamins. Glucose fin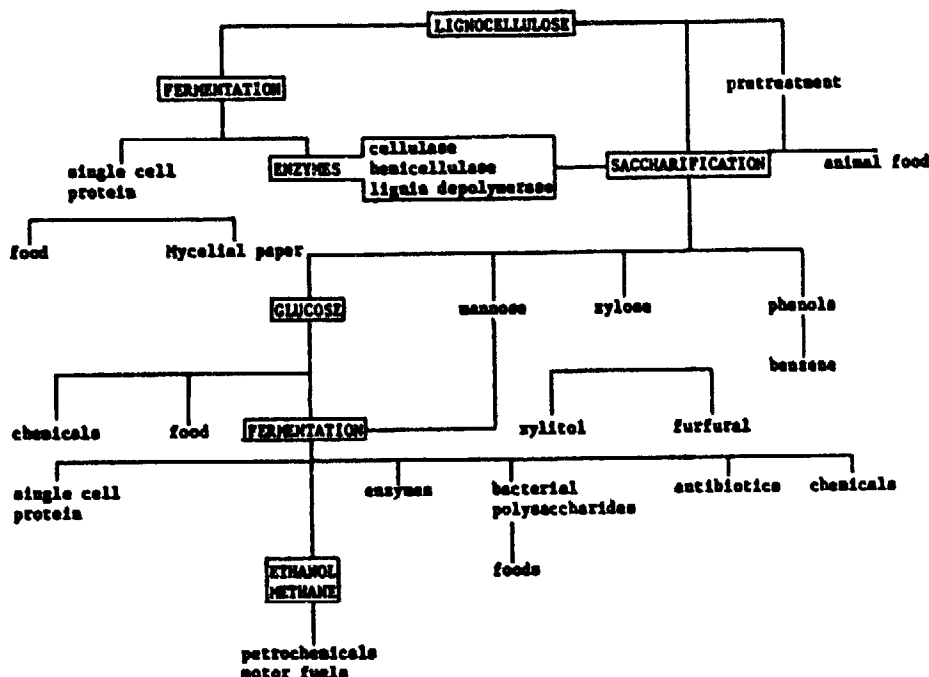ds application in the food, cosmetic and pharmaceutical industries. It can be fermented to ethyl alcohol which provides the possibility to solve fuel-shortage problems, as mixtures of ethanol and petrol can be used in motor vehicles. Cellulose derivatives, such as cellulose acetate and nitrate are used in the production of rayon and of plastics.

Upon hydrolysis, the hemicellulose fraction produces xylose, which can be further converted to furfural and xylitol. Furfural is used in the manufacture of furfural phenol plastics, varnishes, pesticides. Xylose can also be fermented into a mixture of ethanol, acetic acid, 2,3-butadiol and other products.

Lignin has received little attention for its application. However, it can be used for burning purposes or in the preparation of phenols and phenolic derivatives. The following low-molecular-weight chemicals can be derived from lignin: vanilline, methyl mercaptan, oxalic acid, tall oil and turpentine. By modification of the polymeric nature of lignin the high-molecular-weight properties may be used to produce oil-well drilling muds, cement and concrete additives, ore-flotation products, binders and adhesives, rubber additives, tanning agents and plastics.

4.1.5 THE SEPARATION OF SAWDUST INTO ITS COMPONENTS

The chemical processing of sawdust can be carried out by fractionation of sawdust into its components, using pretreatment and solvent extractions. One way to achieve this separation is to apply pretreatment such as steam explosion followed by fractionation at a temperature range of 160-230°C and 450 psi pressure. Lignocellulose materials, such as crop residues and hardwoods, when subjected to high-pressure steam for a certain amount of time, undergo autohydrolysis, and at the same time break down into lignin and cellulose, while hemicelluloses are solubilized and converted into sugars, furfural, acetic acid and other products.

Lignin is modified as to be extractable with caustic soda, leaving relatively pure cellulose. The wood-explosion process is based on the Stake II system (see figure 4.4). It includes a feeder pressurized to 20-25 atmospheres, a reactor and a discharge system. The feeder uses the cellulose as a plug to prevent steam losses in the pressurized reactor.
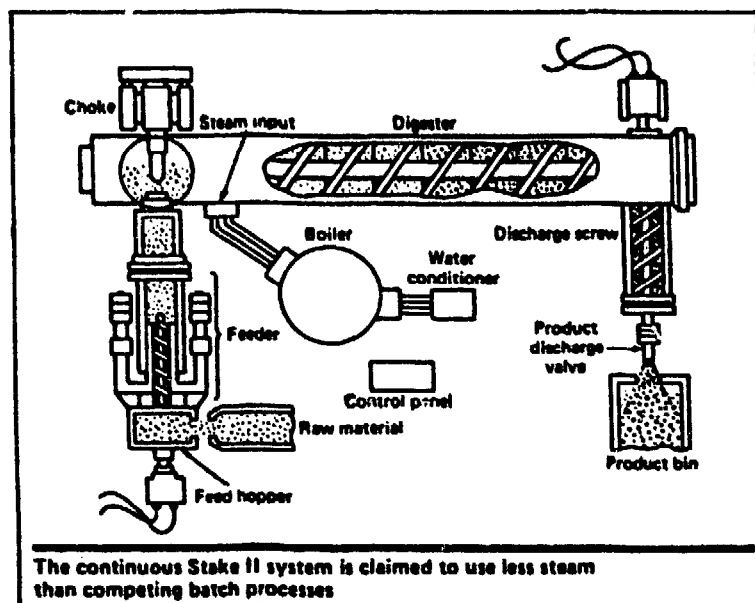

The continuous Stake II system is claimed to use less steam than competing batch processes

Figure 4.4

Once formed, the plug which reaches a density of more than 60 lb/ft^3 is continuously moved forward by the addition of raw material to the feeder. When the plug enters the digester it reverts to its original density (about 20 lb/ft) (3). The finished product is steam blown about every four seconds from the digester through an automatically controlled ball-valve orifice. When passing through the valve, the product is suddenly expanded and dehydrated as a result of both turbulance and pressure differential in the discharge nozzle. The steam explosion also helps to physically break down the bonds between cellulose and lignin. Another recent development in the field of autohydrolysis of wood is the Iotech method in which steam explosion is followed by fractionation of lignin and cellulose with a mixture of a 90/10 ethanol/ water mixture, leaving behind the cellulose (see figure 4.5). This method is developed by Malhotra et al. (1983). The Iotech method is also based on steam, temperature and mechanical shock (500 psi, 200-238°C).

The process of autohydrolysis has been demonstrated to produce high-energy ruminant feeds from a wide range of crop residues and hardwoods (11,12). In this case separation of lignocelluloses is not required. Wood waste after steam explosion is more digestible due to breakdown of the complex structure of lignocellulosic material. In fact continuous autohydrolysis systems are now in operation producing cattle feed at two locations (12).

Work on the extraction of lignin from wood by aqueous ethanol was reported in early literature (13,14). Klienert further improved the method and a process of alcohol pulping was developed which is patented (15). However, high temperatures and high pressures are essential features of all these processes. Another approach for the separation of components of wood is to use organic solvent at a low temperature. The Organosolv method is based on simultaneous hydrolysis and extraction of lignin. When water is added to the system the hemicelluloses are also dissolved. Gast et al. (16) found that n-butanol and ethylene glycol are the most promising organosolv.

WOOD

| explosion treatment

EXPLODED WOOD

water extraction

CELLULOSE RESIDUE   SOLUBLE LIGNIN
                              < 4.1%

        +   +

LIGNIN   HEMICELLULOSES
                              23.1%

alcohol
extraction

LIGNIN   CELLULOSE
19.0%   RESIDUE
(> 90%   53.8%
klason lignin) (72% α-cellulose)

                    MICROBIAL PROCESSING
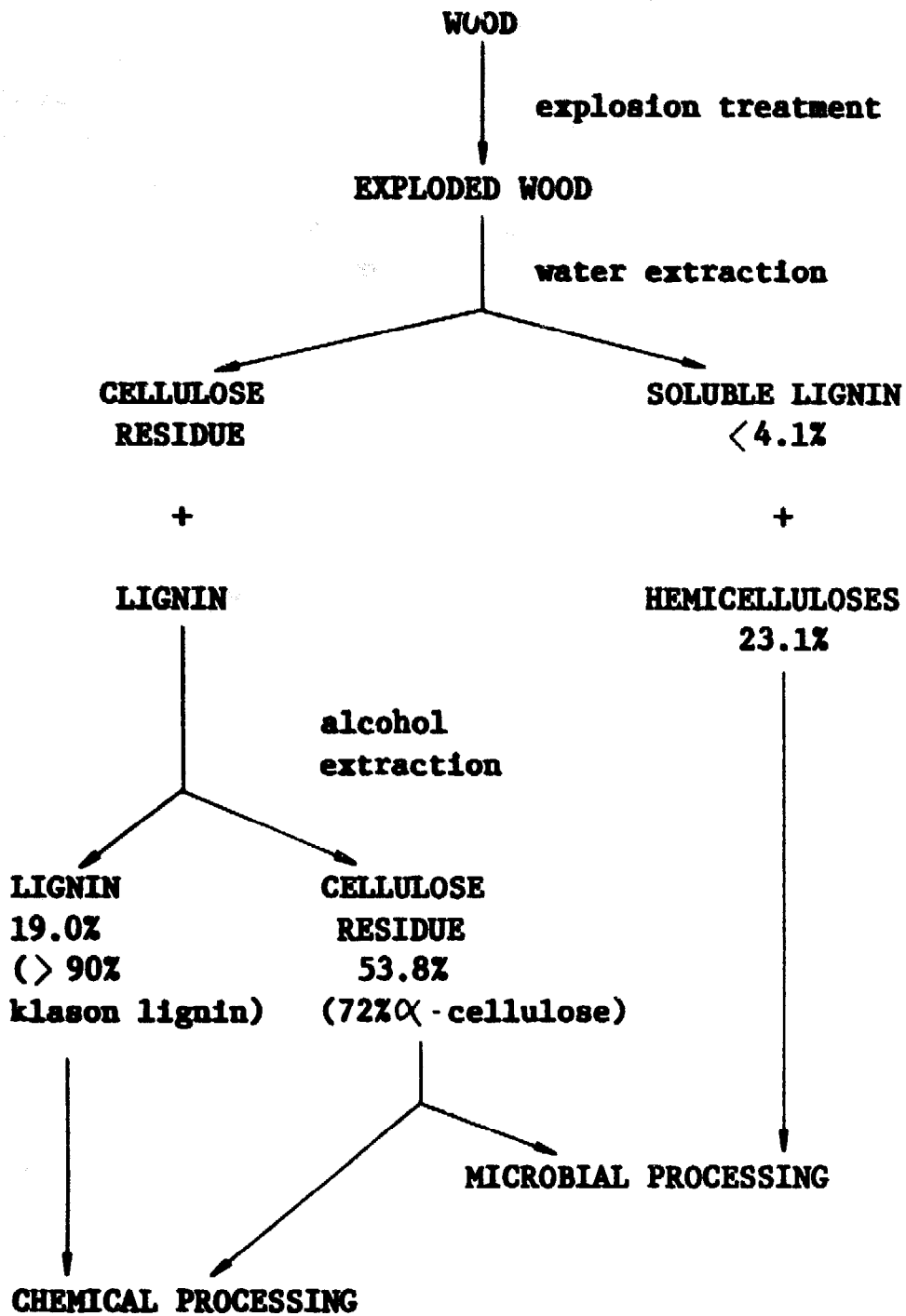
CHEMICAL PROCESSING

Figure 4.5 Schematic flow chart for fractionation of wood
            following treatment by the wood-explosion process

Sacchetto et al. (17,18) at Battelle Geneva Laboratories have developed a process using phenol as a solvent (see fig. 4.6).
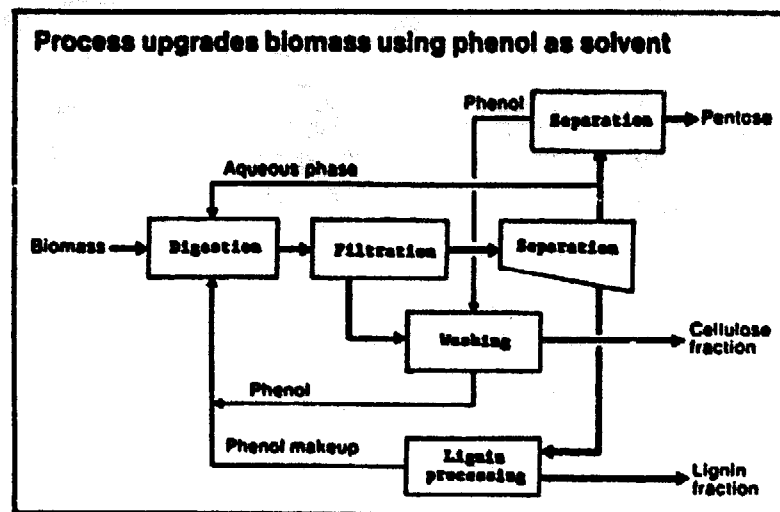

Figure 4.6

A high yield of pentoses is obtained (80-90%) and cellulose and lignin are produced in their original form. The cellulose pulp is obtained at reasonable cost and can be hydrolyzed with acids or with enzymes. Lignocellulosic material is treated with phenol and dilute hydrochloric acid at 100°C and atmospheric pressure. Under these conditions phenol and water are totally miscible with the water phase forming a homogeneous liquid phase in which lignin is dissolved with simultaneous hydrolysis of the hemicellulose. The remaining fibrous cellulose fraction is separated by filtration and the liquid phase is allowed to cool. During cooling the phenolic portion with the dissolved lignin separates spontaneously from the aqueous phase, which contains the pentoses. This way pure lignin is separated, which can be used as a fuel or can be hydrocracked to produce phenol, which can make up for the losses in the process or can be processed further in other chemical industries.

However, it was claimed (17) that these systems accomplish a complete separation of lignocellulosic material, while in steam extraction processes a total separation of lignin is not effected.

4.2 TECHNOLOGY OF WOOD HYDROLYSIS

4.2.1 INTRODUCTION

In principle, it is possible to convert wood into a number of useful products by chemical processing, and this might appear to be a profitable way of utilizing the very large amounts of wood waste that accumulate at sawmills and processing plants. The most promising process consists in hydrolysis of the cellulose and hemicellulose in wood by means of acids to yield a mixture of sugars. Several processes have been devised and put into operation in various countries. These processes have been based on the use of either cold concentrated hydrochloric or sulphuric acid or hot dilute sulphuric acid to bring about the hydrolysis of the polysaccharides. These methods have been recently summarized by Donkersloot-Shouq (1982) (19) in a literature survey.

The produced sugar may be used either directly as a constituent of animal feed-stuffs (molasses) or they may be fermented to produce ethyl alcohol. Moreover they may be used as a substrate for the growth of a fodder yeast, or for the preparation of pure, crystalline glucose. Lignin can be recovered as a by-product of the hydrolysis process. However, in order to be efficient a hydrolysis plant has to be large, relatively complicated and costly, whereas the value of the end-product is low because the sugars can be produced more cheaply from other sources. Consequently the wood-hydrolysis plants that have been set up have not generally been successful, for economic rather than technical reasons. For example, the Scholler (20) wood-hydrolysis process was used in Germany in the second World War, mainly to produce ethyl alcohol for war-time need. Therefore the economics of these plants were of secondary consideration. Two plants based on the Madison process were built in the U.S.A. (21,22), which were later closed down. One plant has been operated in the past in Switzerland with heavy government subsidy, but even this plant was closed down. As far as is known, the only

known, the only country in which there is a substantial wood-hydrolysis industry is the U.S.S.R.

Other processes for producing useful chemicals from waste wood (for instance phenol, furfural) have been investigated but all of them meet the same obstacles and no economically successful process is in sight.

Indeed, it is generally much cheaper to produce these chemicals from other sources, such as wheat straw, oat hulls, etc. or from the petroleum or coal-tar industries.
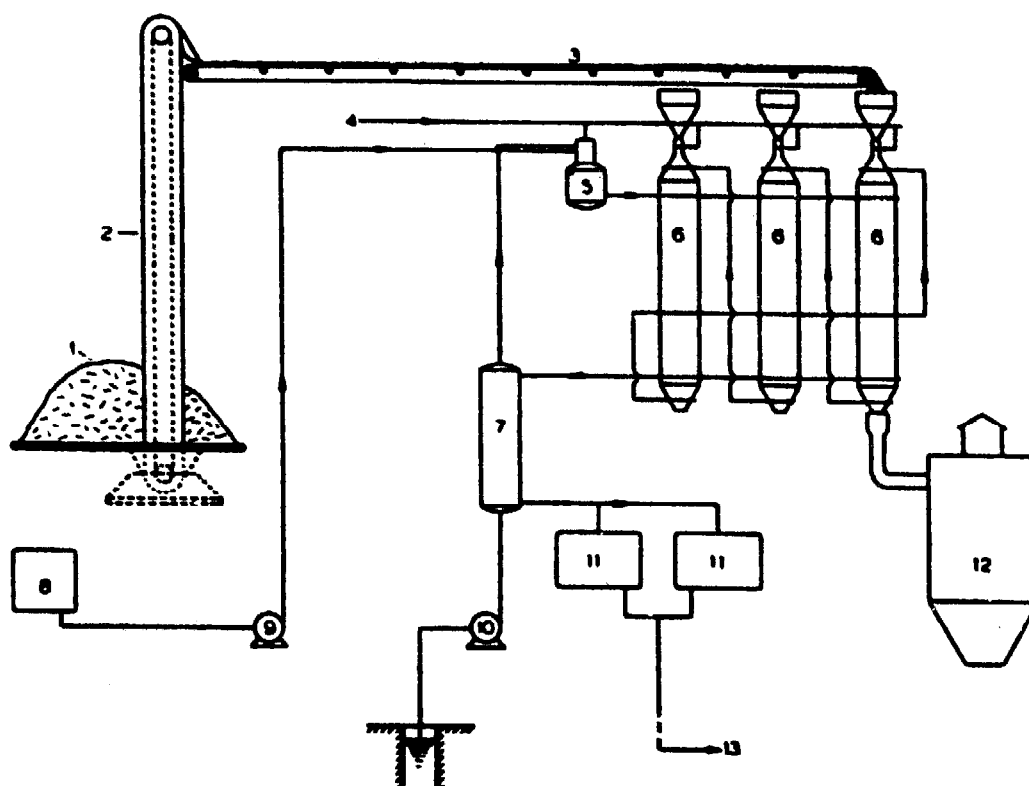
Flow-sheet of the Scholler-Tornesch wood hydrolysis process: 1 wood chip storage; 2 elevator; 3 conveyor belt; 4 steam inlet; 5 purging chamber; 6 percolators; 7 heat exchanger; 8 acid storage tank; 9 acid pump; 10 water pump; 11 storage tank for wood sugar solution; 12 lignin storage tank; 13 wood sugar solution to processing.

Figure 4.7

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4.2.2 CONVENTIONAL METHODS OF WOOD-HYDROLYSIS

The most common wood-hydrolysis process consists of heating wood chips with dilute acid. Although a number (23,24) of other acids have been tested, dilute sulphuric acid has been used for the hydrolysis of wood and wood waste in most industrial plants for a long time.
In general, the process can be described as follows.
The wood chips are filled in a perculator in which the hot acid is added from the top and steam is injected at the bottom of the percolator. Mostly the temperature range is 150-185°C, corresponding to higher than atmospheric pressures. The acid solution drips through the mass of wood between the steam plugs. The acid concentration ranges from 1 to 2.5 wt%. Both batch and semi-batch processes have been used (20) (see figure 4.7).
In the Madison process pretreatment of the wood chips is employed, i.e. they are heated with live steam, before the addition of acid. This is a two-step process, in the first step an acid concentration of 0.5% is used for 30 minutes. Under these conditions the hemicellulose is almost completely hydrolysed. This solution is then drawn off giving a sugar solution with a concentration of about 15 percent. Fresh acid is then added and the temperature is raised to 180-185°C, whereupon the cellulose hydrolyses to glucose. The yield of glucose is 50 percent. The total time for this reaction is three hours. The hydrolysate solution is neutralized with calcium carbonate. After filtration and cooling to the desired temperature glucose can be recovered from the solution by crystallization, or the hydrolysate can be passed to a fermentation tank where yeast and its nutrients are added and the fermentable sugars are converted to ethyl alcohol. About 28-30 kg crystalline glucose can be obtained from 100 kg of dry wood. In the one-step process the hydrolysate is a mixture of various sugars. In some plants only wood sugars (molasses) were produced, to be used directly for fodder.

4.2.3 NEW METHODS FOR AGRICULTURAL RESIDUES AND WOOD WASTE

Sawdust can be hydrolysed with acids in the same way as wood is hydrolysed. However, it is difficult to percolate acid through a substrate of sawdust. The same problem is encountered with agricultural waste. Therefore new process designs are needed, which can be applied to any lignocellulosic waste. At present, a method of continuous acid hydrolysis is being developed by Converse et al. (25) to deal with such a substrate. Characteristic parameters are: a temperature above 180°C, a short reaction time and dilute sulphuric acid as catalyst. Solid substrate and a liquid phase are introduced together as a slurry to the reactor. The glucose yield is 50-60 percent.

In another method (Church et al. (26)) a 1.5 inch diameter isothermal plug-flow pipe reactor, fed by a high-solid twin-ramp pump is used. Coarse sawdust at 35 percent input solid is hydrolysed at 200-225°C. For instance, oak sawdust was hydrolysed with 1.5 wt% sulphuric acid and 4.5 minutes residence time. Glucose yields of 40-42 percent of the theoretical amount were obtained. These methods, however, have only been applied on a laboratory scale.

In a two-stage process separate xylose and glucose solutions are obtained. A high-solid slurry can be used in these reactors.

Immediately following the high-solid pump, there is an injection block to allow the introduction of high-pressure steam and sulphuric acid. The hydrolysis takes place instantaneously (27). At the severe hydrolytic conditions required for the hydrolysis of cellulose and at the high temperatures necessary to form glucose (using dilute acid) a large portion of the product is converted to by-products such as 5-hydroxymethyl furfural. Alternatively, hemicellulose can be hydrolysed first under mild conditions to produce and to extract xylose. Subsequently cellulose can be hydrolysed to glucose.
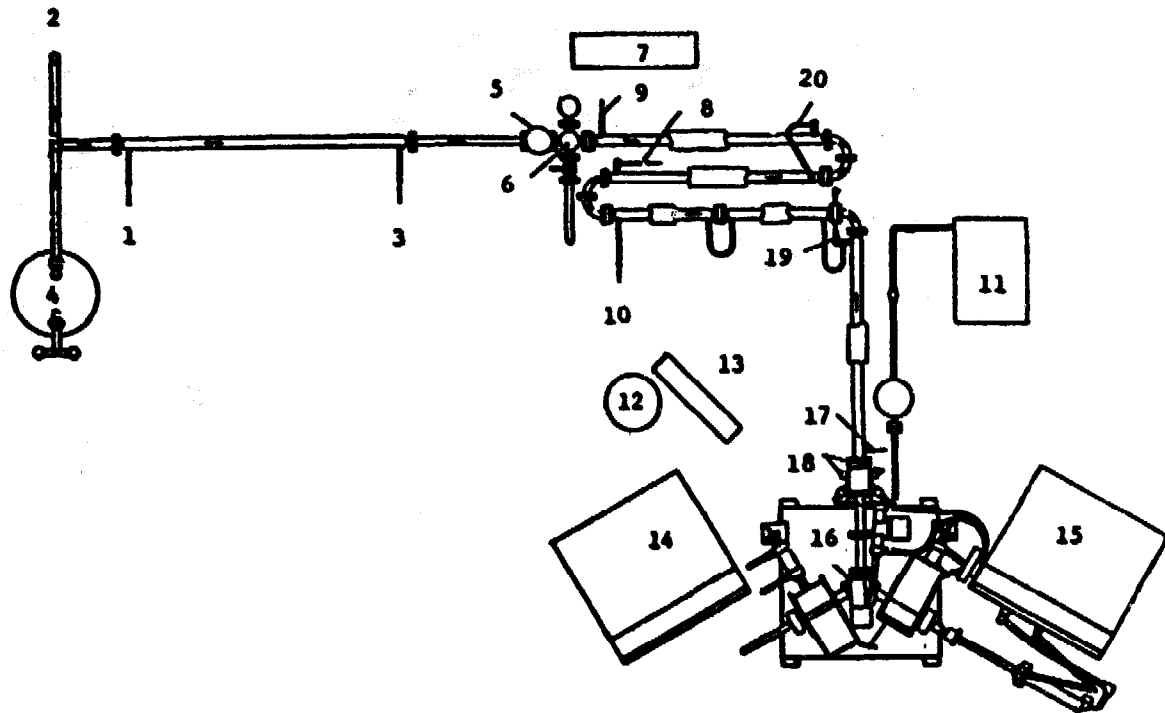
1 water outlet; 2 outlet; 3 water inlet; 4 receiving tank; 5 process valve; 6 air chamber; 7 oil heater; 8 oil out; 9 oil in; 10 oil in; 11 boiler; 12 acid storage tank; 13 acid pump; 14 hydraulic power unit; 15 hydraulic power unit; 16 ball valve; 17 oil out; 18 to acid pump; 19 pressure transformer; 20 oil jumpover.

Figure 4.8   Continuous high-solids biomass-hydrolysis reactor

4.2.4 SAWDUST HYDROLYSIS, A PILOT PLANT STUDY

A method for continuous acid hydrolysis in which sawdust is used as a raw material has been developed by Rugg (28). Originally the New York University continuous acid-hydrolysis process had been used primarily for the conversion of crystalline alpha-cellulose to glucose (29). At the high temperature required for this process the amorphous hemicellulose fraction, mainly composed of pentosans in hardwood, is converted beyond the sugars to furfural. A recent experiment demonstrated the feasibility of a continuous two-stage hydrolysis method which would allow for a more complete utilization of the carbohydrate content. Schematically, the process is shown in figure 4.8. By using mild prehydrolysis and extraction it is possible to reclaim a major portion of the hemicellulose fraction as xylose. Subsequently a continuous hydrolyzation converts the remaining hexosan fraction to glucose in the usual way.

Even more recently (30), studies at New York University have resulted in the design, costing and construction of a continuous waste-cellulose-to-glucose pilot plant with a normal capacity of 1-2 tons per day. This pilot plant employs an intensive screw mixer/conveyor for continuously converting waste cellulose at high temperatures in the presence of acid. The key to successful operation of this process is the design of the hydrolysis reactor. This reactor must be capable of feeding, conveying and discharging hydrolyzable cellulose materials continuously, while maintaining an appropriate temperature and pressure in the reaction zone. Because this hydrolysis requires exposure of the reactor components to dilute acids at high temperatures and pressures, all construction materials have to be resistant to corrosion especially in the reaction zone. The particular reactor chosen was a Werner & Pfleiderer ZDSK 53 (53 mm) twin screw extruder. Conversions of 50-60% yield based on available alpha-cellulose have been reported. Experiments have been run with divers feedstocks such as paper pulps (10% solids) and hardwood sawdust (95% solids). Significant increases in yield with improved process controll are anticipated.

4.2.5 DERIVED CHEMICALS

4.2.5.1 ETHYL ALCOHOL

The fermentation of sugars to ethanol is one of man's most ancient arts. Commercially proven techniques can provide yields of 85-95% of the theoretically possible along with by-products yeast and carbon dioxide.

$$C_6H_{12}O_6 \xrightarrow{\text{fermentation}} 2C_2H_5OH + 2CO_2 + \text{yeast}$$
$$\text{glucose} \qquad\qquad\qquad\qquad \text{ethanol}$$
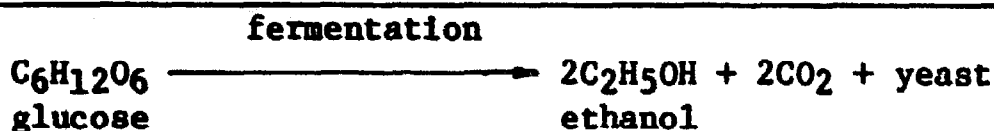
The fermentation of sugar to ethanol is carried out by the conventional method (31) (see figure 4.9). The neutralized hydrolysate consists of a 10% sugar solution (hexoses). It is fed into the fermenter, along with yeast and its nutrients. During fermentation the temperature is kept at 33°C, the pH at 4.5 to 5. Fermentation takes place for about 58 hours. After this period a beer containing 6-7% of ethanol is produced. The yeast is recovered and recycled, the ethanol is recovered by conventional distillation and dehydration methods. The stillage residue is evaporated to 50% total solid and can be used as animal feed. The process for the production of ethanolic fuels is simpler than those required to make beverage-type alcohols or pure alcohols for other purposes. 95% Ethanol can be used directly as a fuel for motor vehicels (32).

The ability to produce ethanol from glucose is widely distributed among various micro organisms; however, the yields vary considerably from almost 2 mols of ethanol per mol glucose fermented, characteristic of yeast, to much smaller amounts produced by numerous bacteria (33). Zymomonas species give a fermentation balance which is similar to that
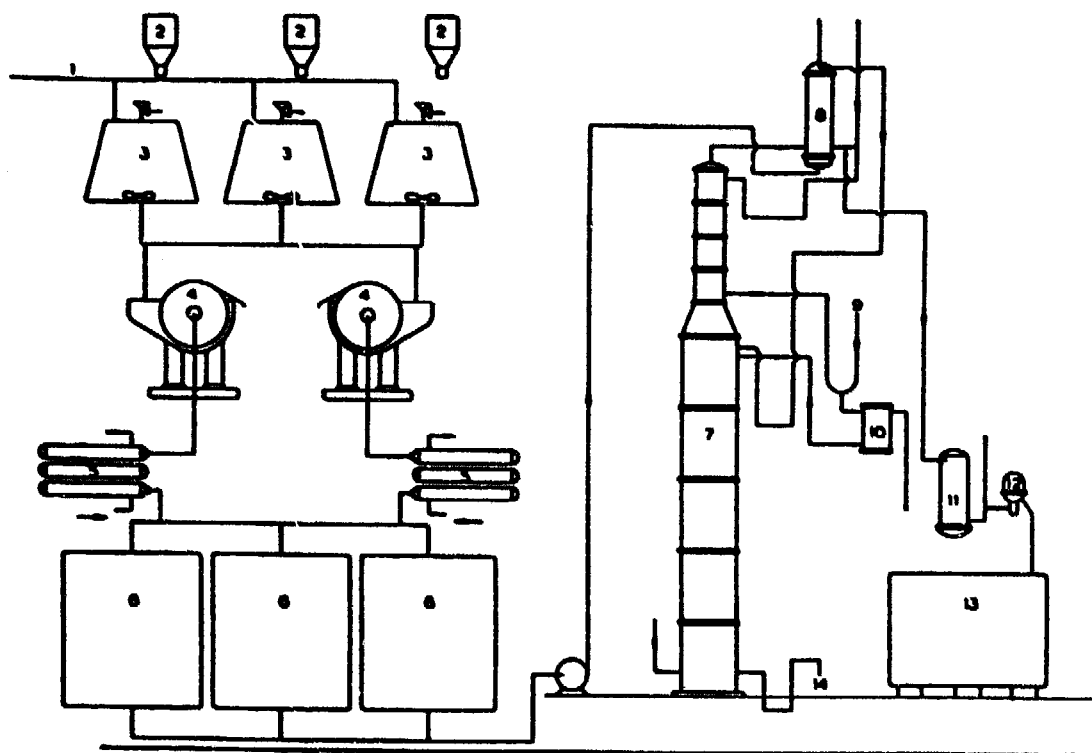
Processing of the wood hydrolyzate: 1 hydrolyzate from percolators; 2 neutralization medium; 3 clearing vats; 4 filters; 5 coolers; 6 fermentation; 7 distillation; 8 preheater-condensator; 9 water inlet; 10 separator; 11 cooler; 12 alcohol separator; 13 alcohol storage tank; 14 alcohol-free wort.

Figure 4.9

of yeast. The conversion of glucose to ethanol by yeast fermentation is well understood in terms of technology and product yield.

Clostrium thermocellum is utilized to ferment cellulose directly to ethanol and acetic acid (34). Bellamy and Brooks et al. have persued the production of both single-cell protein (SCP) and alcohol from agricultural wastes by utilizing various biological conversion processes. The process (34,35) involves a steam pretreatment to partially delignify wood and

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enhance the accessibility of cellulose to microbial utilization.

At present ethanol is produced commercially from petroleum. It is a basic chemical feedstock for various chemical industries. About 1.5 billion lbs. are being produced synthetically each year in the U.S.A. by hydration of ethylene. The reverse reaction, the dehydration of ethanol to ethylene, while uneconomical in competition with cheap ethylene from petroleum, proceeds in 96% yield and was practical commercially many years ago (35). Similarly, butadiene can readily be obtained (34) from ethanol. Ethyl alcohol is also used as a fuel, when mixed with petrol (gasohol).

4.2.5.2 YEAST

Yeast can be produced from wood-sugar solution. The nutrients are added to the hydrolyzate. Ammonia, ammonium sulphate and ammonium phosphate are used as a nitrogen source. The wood-sugar solution is neutralized to pH 4.5 to 5. The filtered solution is then passed into fermentation vats. The yeast is added and the fermenter is aerated, whereupon the sugars are converted to Torula yeast by an aerobic fermentation process (36). The yeast cream is separated, the solid yeast product is packaged in bags and ready to be sold as a feed supplement. This product contains about 45 percent protein (32).

4.2.5.3 FURFURAL
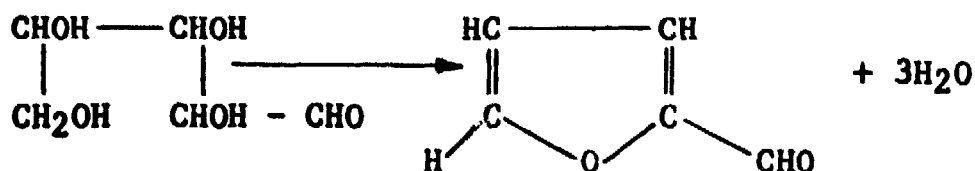
Furfural is an excellent solvent, widely used in industry. It is a solvent for waxes and for cellulose esters. It is also a selective solvent for the purification of animal, vegetable and mineral oils and for wood resins. With phenol it forms heat-resistant condensation products. It is used in the plastic and the paint industries and it is an important raw material for the production of nylon.

Furfural is prepared as follows. When strong acids react with
pentoses, water is split off with the formation of furfural.
Xylose can be converted almost quantitatively to furfural.
Pentoses (xylose) can be obtained by the acid hydrolysis of
pentosans (hemicellulose) as described in the previous
sections.

$$(C_5H_8O_4)n + nH_2O \longrightarrow nC_5H_{10}O_5$$

1. Hydrolysis of pentosans to pentose.

$$\begin{array}{cc} CHOH & CHOH \\ | & | \\ CH_2OH & CHOH - CHO \end{array} \longrightarrow \quad + 3H_2O$$

2. Dehydration of pentose to furfural.

The majority of hardwoods contain a considerable amount of
pentosan. Hydrolyzates of this type of wood therefore contain
more or less large amounts of furfural, depending upon the
pentosan content. In a two-stage hydrolysis the pentoses are
enriched during the prehydrolysis. Furfural is recovered by
steam distillation (37). Furfural can be produced directly by
moistening the raw material with 7-10% sulphuric acid and
subjecting the mixture to steam distillation. The escaping
steam is blown into a cyclone and the condensate is distilled
to give three fractions. The yield of furfural from oat hulls
is 10-11 percent, only about half of the optimum yield of 23
percent. On this basis sawdust will give a furfural yield of
only 3.6 percent.

Industrially, furfural is produced from oat hulls (with the Quaker Oats Process) and corn cobs (38). The cost of production from these resources is low, as they contain large amounts of pentosan. It is clearly not economically feasible to make furfural from sawdust, as compared with the existing process. However, it can advantageously be produced as a by-product of the acid-hydrolysis process by prehydrolysis of the material (as described in the previous sections).

4.2.6 CONCLUSION

From the present study it is clear that no truly simple and economically feasible wood or sawdust hydrolysis process is yet available. No single product is sufficiently valuable to pay the cost of raw material, collection, handling and processing. If hydrolysis processes are to play an important part in the utilization of waste wood, a fuller utilization of raw material must be realized.

Due to the recent interest in the utilization of waste wood and agricultural waste, research is carried on in a number of countries. As a result some interesting developments are on the way, but more research is needed in the field of acid hydrolysis of sawdust. Only when the first step, i.e. the hydrolysis of sawdust into sugar can be achieved in an economical way, one can proceed further towards converting sugars into chemicals which can be utilized as a feedstock for the chemical industry.

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4.3 MISCELLANEOUS

4.3.1 WOOD EXTRACTIVES

In addition to the main structural components of which the wood cell walls are built up, all woods contain smaller amounts of minor or extraneous components which can generally be extracted from the wood with organic solvents or sometimes with water.

4.3.2 TANNINS

Several products are obtained from wood by extraction with water or organic solvents. Among these are the tannins, which have the main use in the tanning of hides and skins (54). To be suitable sources of tannins for use in leather manufacture, woods should contain appereciable quantities of water-soluble tannin which at the same time is capable of producing a light and pleasant color in the leather tanned by it. For extraction, wood must be fairly finely divided (55). Tannin is present in the wood and bark of many species of trees mainly hardwoods, and a few are used for tannin production. Extraction of tannin from oak wood for use in leather manufacture has been carried out in the past, but oak has a relatively low tannin content, (average about 10%) in comparison with other sources, Quebracho wood and wattle bark contain 20-30% of tannin. Mostly water is used for the extraction of tannins. The sawdust from these wood species might also be of value for the tannin extraction (55,56).

4.3.3 TURPENTINE AND ROSIN

Turpentine and rosin are among the most important of wood extractives. Sawdust (or wood chips) are extracted by means of suitable solvents (petroleum, naphta or benzene). The solvent is first recovered from the extract by distillation, and the turpentine is then separated from the rosin by treatment with steam. The process utilizes largely stumpwood from the trees that have previously been felled, which is rich in resins and oils. Southern pine wood stumps that are first reduced to small chips are used to produce pine oil and turpentine. It is possible that this process could be applied to sawdust provided the yield obtainable and supply of raw material justify the cost of equipment.
Sawdust of special trees (which are rich in resins and oils, such as pine) could be used for such purposes.
Turpentines are used as a solvent in paints, and for producing fragrances, insecticides and pineoil. Rosins are used for paper sizing and in other chemical industries.

4.3.4 ESSENTIAL OILS

A number of oils such as Cedarwood oils, Sandalwood oils, Sassafras oils, etc. are obtained by steam distillation of the wood or other parts of certain trees. Sawdust from these trees can be applied to steam distillation to recover these oils.
These oils are used in perfumery and in medicine.

4.3.5 VANILLIN FROM SAWDUST

Vanillin is an important pleasant-smelling compound. It is used for the flavouring of confectionery, baked goods, candies, and ice creams. It is a starting material for a large number of compounds of commercial importance.
Vanillin can be synthesized from Eugenal by a mild oxidation

reaction. The source of Eugenal is clove oil and cinnamon oil. These sources are costly and not reliable.

Vanillin can be produced from softwood sawdust especially spruce and pine sawdust, for example (cedrus deodara) sawdust is commercially used for the distillation of essential-oil. After the essential oil recovery the sawdust is disposed of as a fuel. The sawdust left after distillation of essential oil can be used as a source of lignin for the preparation of vanillin.

The following experiment was carried out on a laboratory scale (57). Oxidation of sawdust was carried out in an alkaline medium using various reagents such as nitrobenzene, capric acid, copper sulphate and air. The sawdust was heated with reagents under suitable reaction conditions in an autoclave. The alkaline reaction mixture after removal of oxidising agent is acidified and filtered. The filterate is then extracted with benzene or chloroform, vanillin is separated from the concentrated extract and subsequently purified by crystallization. See tabel 4.3.

Table 4.3.

Yield of Vanillin from Alkaline Oxidation Studies on Sawdust.		
Sl. Material No.	Oxidant	Yield (Klason Lignin basis) (%)
1 Deodar sawdust (oil extd.)	$PhNO_2$	6.5
2 Deodar sawdust (oil extd.)	CuO	3.5
3 Deodar sawdust (oil extd.)	$CuSO_4$ & air	6.1 - 7.2
4 Deodar sawdust (oil extd.)	Air	6.6 - 7.0
5 Spruce wood sawdust	$PhNO_2$	6.5
6 Spruce wood soda lignin	Air	3.3
7 Spruce wood sawdust	Air	4.95
8 Fir sawdust	CuO	1.75 - 2.04
9 Pine sawdust (alcohol/benzene extd.)	CuO	2.1

The bulk of vanillin is manufactured from lignin available as lignosulphate, which is a by-product of sulphite-pulp mills. The technical process is a well-guarded secret of the manufacturing companies (57). For technical and economical reasons the lignosulphate of coniferous wood species is oxidised to get vanillin. The yield of vanillin varies between 5-6 % on lignin basis.

4.3.6 OXALIC ACID

Sawdust was formerly used for the manufacture of oxalic acid. The alkali fusion of sawdust for the production of oxalic acid is an old method (31). Good yields are obtained with the ratio of alkali to wood 2:1 and at a temperature of 240-250 °C. The sodium oxalate is leached out from the melt and the solution is concentrated and allowed to cristallize. The sodium oxalate is treated with hot milk of lime to give calcium oxalate, which is decomposed with sulphuric acid to yield oxalic acid. A mixture of potassium and sodium hydroxide for the fusion is preferred to sodium hydroxide alone. Oxalic acid is produced cheaply nowadays from other resources. So the alkali fusion process has lost much of its significance. Oxalic acid is commercially synthesized by nitric acid oxidation of carbohydrates and from ethylene glycol (58). However, technically it is possible to produce oxalic acid from sawdust.
Oxalic acid is used for metal cleaning, textile, dyes, flameproofing, plastics.

4.4 TECHNOLOGY OF PULP - AND PAPERMAKING

4.4.1. INTRODUCTION

Paper is an important commodity, used in all countries of the world. Indeed, the consumption of paper and paperboard is said to provide a certain criterion for the degree of civilization of a country.

The world consumption of paper is increasing. Paper and paper board are used for a great variety of purposes, but two main consumer groups can be differentiated in printing and writing, and packaging. A major component of the first group is newsprint, which consumes about half of the total production of printing paper.

The starting material for the production of paper and paperboard is wood, from which pulp is produced by various methods. The main methods for the preparation of pulp from wood will be summarized in section 4.3.2 of this chapter. Traditionally, the wood-pulping industries have been based on wood chips as a raw material. However, already in 1926, in the Pacific Northwest of North America a pulpmill designed to use sawmill residue was put into operation (39). Nevertheless it is fair to say that only in the 1960s the pulping of sawdust and indeed of other small-particle wood material (including small-diameter forest residues from logging, thinning and agricultural and plantation-clearing operations) became of practical importance. Apart from the obvious economic advantage of using wood waste as a raw material rather than the full body of the tree, the saving of energy and time and the decrease of problems with the disposal of solid wood waste were also important considerations. In addition, the profitability of most sawmills is tied heavily to the value of their residue. Excluding bark, about 55 percent of a saw log is residue, about 10 percent shavings and 35 percent chippable material. For some sawmills all of the residues is disposed of by incineration or landfill, i.e. it represents a negative value. This is especially the case during times of

high lumber demand and low pulp and paper demand (39,40).
However, the use of sawmill residues, and in particular of
sawdust, as a cheap basic material for pulp production is not
altogether straightforward. Especially the small particle size
of sawdust may cause problems in storage devices as well as in
the actual pulping process and also the properties of the
product pulp are negatively affected by the short fiber length
characteristic of sawdust (52). Research on these problems is
still going on and has been reviewed in section 4.4.5 of this
chapter.

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4.4.2 GENERAL METHODS OF PULP PROCESSING

In general, the need for pulp preparation as a stage in paper-making is based on two separate aims. The first is to produce pure cellulose as is necessary for a particular type of paper, the second is the removal, to the extent necessary, of all dust, grit and other extraneous matter, which is contained in the fibre as it arrives at the pulping mill.
The following methods can be applied for pulpmaking (31).

4.4.2.1 CHEMICAL PULPING

The purpose of chemical treatment is to reduce chips to component fibre to produce pulp of a colour good enough for papermaking. Chemical pulps have low lignin and hemicellulose contents, as these components are dissolved during chemical digestion. In pulp produced by a chemical method the fibres are undamaged and strong. Chemical pulps are used mainly for strength and performance in a variety of paper and paperboard products.
There are two different methods for the production of chemical pulp. The first one is the sulphite process, the second one is the sulphate, or kraft process.

4.4.2.1.1 The sulphite process

This method is used extensively for the treatment of spruce wood, though not restricted to it. In this method the wood chips are treated with a solution of calcium bisulphite and free sulphur dioxide in a large digester at a pressure of upto 100 psi at a temperature of 170°C. The cooking period may be from 6 to 24 hours, according to the type of pulp required, the strength of the liquor used and the operating pressure. The liquor is formed by spraying water on limestone. The digestion reduces the wood chips to 55 percent as cellulose is dissolved to some extent at the same time as the non-cellulosic material. The spent liquor consists largely

of calcium lignosulphite, which is a difficult effluent to
dispose of. The spent sulphite liquor is separated and sub-
jected to special processing. As anti-pollution laws are get-
ting more strict, it is becoming necessary to recover the
chemicals from spent sulphite liquor, which used to be simply
disposed of into the river.

Soluble sodium-base sulphite is also used for making pulp from
wood chips. The range of application with regard to various
wood species is wider in the case of water-soluble bases than
with calcium-base liquor. A pulp obtained by sodium hydroxide
or sodium carbonate alone is called soda pulp.

4.4.2.1.2 The sulphate or kraft process

The kraft pulping process can utilize practically all types
of wood species. This is the main process for producing
chemical pulps. A solution of sodium hydroxide and sodium
sulphide are used and the yields are 46 to 55 percent. The
time of digestion is usually 3 to 5 hours at a pressure of
120 psi. About 15 percent of the active alkali is present as
sulphide. The higheryield pulps contain about 10 percent
lignin; they are used in bags and linerboard where strength
is important. The loweryield pulps are bleached to remove
almost all lignin and to produce brightness (90). These pulps
are used where permanence and whiteness are needed in addition
to strength (53).

The bleaching of the originally dark-coloured pulp has been
improved to such an extent that kraft pulp can be used for
practically all kinds of paper. At the conclusion of the
digestion the pulp is blown by the pressure of the digester
into the blowtank where, through the release of pressure, the
chips are defibered. The black liquor is separated from the
pulp, as far as possible without diluting, and passed into
the storage tank. These pulps are washed thoroughly and are
bleached with chlorine and other reagents. With the blowing
of the digester the pulping process is practically complete.
All subsequent operations deal with the processing of the

pulp and the recovery of the chemicals from the black liquor.
For alkaline pulping both batch and continuous cooking processes are used. The batch cooking process is the classical
form of the alkaline pulping process, regardless of whether
it is carried out with or without a sulphur component. In
developing countries, the batch process will be useful as it
is easier to operate than the continuous process.

4.4.2.2 MECHANICAL PULPING

In mechanically produced pulp, the fibres are separated by
mechanical action. Because there is no chemical removal of
wood components, the process results in a high pulp yield
(95%). The chemical composition of mechanical pulp is similar
to that of native wood, i.e. the pulp contains significant
amounts of lignin and hemicellulose in addition to the basic
cellulose component of the fibre. In the stone-ground wood
process, fibres are separated from wood by grinding logs
against revolving stone wheels, while water is sprayed on the
logs. In this process the fibres are fractured and much debris
is formed. These pulps are used when opacity and good printing
are needed. The presence of a large amount of lignin however
results in poor light stability, permanence and mechanical
strength. Such pulps are bleached with the alkaline hydrogen
peroxide sequences that maintain high pulp yield.
Newer methods of mechanical pulp production involve disc
refiners (R.M.P.). Chips are passed between closely spaced
revolving discs and the fibre is broken free from the wood
material. These pulps contain less debris and longer fibre
than stoneground pulp. They are produced at atmospheric
pressure, and are mixtures of fibres and water in ratio of
1:100. These pulps, after slight reduction in water content,
are fed into the paper mill or the pulp is further dried and
the sheets are made to be sold.

4.4.2.3 THERMOMECHANICAL PULPING (T.M.P.)

This process was first commercialized in Sweden in 1968 (41). Chips are steamed at 120°, prior to fiberization in a pressurized disc refiner. Thermomechanically produced pulp consists of longer, less damaged fibres and less debris, which results in improved strength. These pulps can be used to reduce or eliminate chemical pulps in many blends. Softwood pulps produce optimum strength in the product. In the Netherlands the woodpulping mills use only the T.M.P. method, because the pollution regulations are strict and the chemical pulping methods are costly.

4.4.2.4 SEMICHEMICAL PULPING (S.C.P.)

This method combines the mechanical process and a form of chemical treatment. The wood chips are first treated with steam and little sodium hydroxide or sodium sulphate and are then disintegrated mechanically. Yields are 70-80% and the pulp contains a great deal of impurity and ligneous matter. The main use of this pulp is in corrugated media, in which the stiffness resulting from the lignin and hemicellulose is an advantage. Hardwoods usually are the base woods for semi-chemical pulp. The pulp is unsuitable for any paper of quality or durability. It is used together with better fibres in papers of moderate quality.

4.4.3 THE CONVERSION OF SAWDUST INTO PULP

Important for the use of sawdust as a basic material for the pulp industry is its short average fibre length. The average length of softwood fibre is 3 mm, whereas that of hardwood is 1 mm. The average fibre length of sawdust pulp (from various species of softwood) is 1.2 mm. From short-fibre-length materials one cannot produce pulp of good quality(31). The strength as well as various other physical properties of the resulting paper will be negatively affected.

At present the pulp for making paper is mainly produced from woodchips from softwoods. Mixed pulp from both hardwoods and softwoods are also used, especially in tropical areas where hardwood forests are found. It was shown in a survey that mixed tropical pulps in practice are added in only a small proportion to the total furnish of softwood pulps in Brazil, India, Japan and in the Philippines (42).

The adverse properties of pulp made from sawdust as resulting from the short fibre length can be reduced in two ways. The first and obvious way is to make sure that the sawdust is coarse, as produced by a broad-bladed saw. This requirement points in the direction of an integrated sawmill/pulpmill system. The second way to make good-quality paper out of sawdust is to make use of mixtures of sawdust pulp and pulp of coarser wood material. In fact the serious investigation into the feasibility of sawdust as a source of inexpensive fibre began in the 1960s with extensive research on the properties of pulp mixtures. Lauer et al. (43) made use of sawdust of loblolly pine and gum for the preparation of viscose-grade pulp. Dahm (44) showed that upto 10 percent of the coarser type of sawdust can be added to ordinary shavings sulphate pulp without appreciable reduction in pulp quality. Addition of sawdust bisulphite pulp to mechanical pulp improves strength and drainage, but reduces opacity. Use of +4 mesh bamboo dust for rayon-grade pulp was reported by Gupta et al (45).

Chawla et al. (46) tried various pulping methods on fir saw-dust, such as prehydrolysis followed by sulphate pulping and nitric-acid pulping, all on laboratory scale. Sulphate sawdust pulp was mixed with long-fibred pulp, which was then beaten in the Lampen mill to freeness of 300 ml C.S.F. Standard sheets of 60 g/m^2 were prepared and the strength properties determined. Their conclusion was that long-fibred pulp can be mixed with 25 percent of sawdust pulp for making paper with fairly good strength properties.

The thermomechanical pulping (T.M.P.) method has been suggested for the total sawmill residues consisting of sawdust and shavings as well as chips. The use of sawmill residues in the pulping industry has been increasing in Canada and the U.S.A. and in particular there was a rapid growth from 1960 till 1970. T.M.P. represents an attractive outlet for sawmill residues. A wide assortment of raw materials have been evaluated both commercially (47) and on a laboratory (48) scale. In North America in an number of T.M.P. mills sawdust and shavings are used for making pulp. Uptill now the T.M.P. method has only been exploited by the pulp- and papermaking companies. However, now the technology is well-established and there is an excellent opportunity for the smaller forest-products companies to use T.M.P. for market pulp. It is suggested by Styan (39,49) that the T.M.P. method has an advantage over chemical pulping, where economic reasons dictate large units. Due to the large optimum size of the kraft mill (a minimum production of about 800 tons per day) and the low fibre yield, large quantities of raw material (about 1700 tons per day) are required. If this amount of fibre is required as sawmill residue, then because of the centralization of chemical pulpmills a significant portion of residue must often be shipped over relatively long distances. The residue output of the sawmill is much better suited to supplying material for refiner mechanical pulp or T.M.P. (about 200 tons per day).

4.3.4 CONSTRAINTS AND OPPORTUNITIES FOR MECHANICAL PULP

During the 1950s and 1960s the social and economic climates were favourable for the growth of chemical pulping because the ecological problems had not yet been translated into an operating and capital cost. Chemical pulps are of very high quality, therefore marketing was not a problem. Non-integrated papermills were, and still are, designed to use chemical pulps, but pollution regulations and standards are now well-established and chemical pulping methods are at a distinct disadvantage with regard to both water- and air-pollution standards, as they have to add costly primary and secondary waste-treatment systems. With mechanical pulping there is no need for chemical recovery and the high pulp yield results in low dissolved-solids levels in the effluent. On the other hand, quality control of input material is more important for T.M.P. than for chemical pulping. Dirt and grit affect refiner-plate wear markedly and thus increase operating cost. Moreover, energy consumption is high in all mechanical pulping.

To reduce the cost of fibre for T.M.P., a furnish of 75 percent of chips and 25 percent of (coarse) sawdust is advisable. A 250-thousand-board-feet-per-day sawmill could supply sufficient sawdust for an economically sized T.M.P. mill.

Further literature analysis indicates that chemical pulping (kraft pulping) of sawdust is also feasible on a commercial scale. In 1979, in the U.S. and Canada, M&D continuous digesters alone accounted for more than 7000 air-dry tons per day of kraft pulp, produced from wood waste, including sawdust (50). Many sawdust-pulping systems have been designed to enable a fast changeover to pulping of hardwood or softwood chips in order to meet a mill's changing requirements. However, more pulpmills will find it economically feasible to install a separate sawdust-pulping system because of increased availability of sawdust and other wood residuals.

For unbleached kraft pulp, the yield from sawdust is 46-48%.

The inclined-digester technique, which is being used for saw-dust-pulp production, permits maximum flexibility in utilization of the digester unit and is reported to produce maximum potential pulp quality. Sawdust-pulp strength characteristics have been found to meet 83 to 85 percent of those of pulp from chips of the same wood. Blends of 17 to 20% of bleached saw-dust pulp have been added to fine papers with no adverse effects on paper strength. As much as 30 percent of sawdust
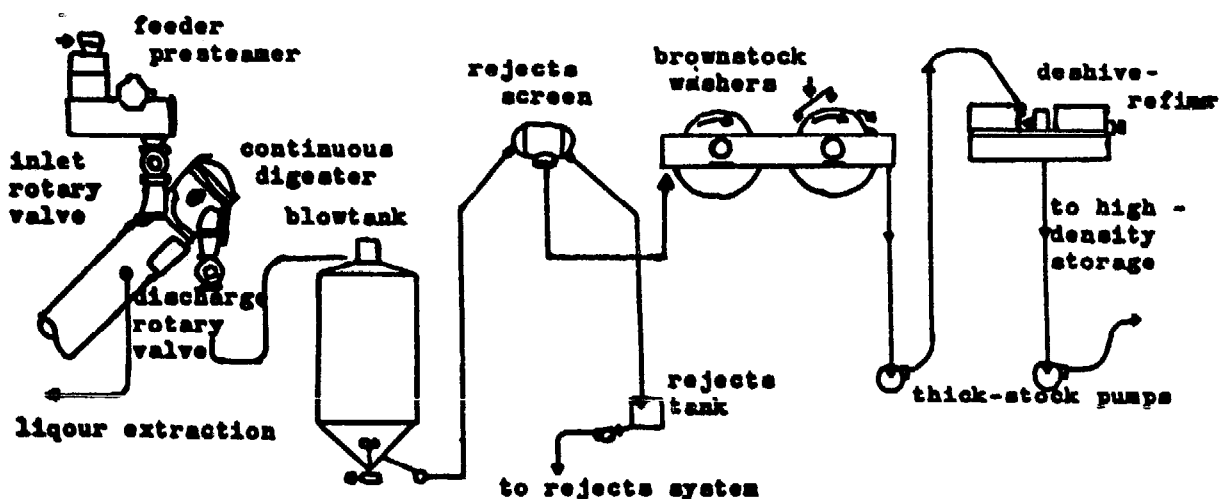

Fig. 4.10 Flow sheet of a bleachable-grade pulping system for sawdust and wood residues

pulp is blended into unbleached bag paper and paperboard, and 50 to 70 percent of sawdust pulp is successfully blended into towelling and tissues.

Another argument for the installation of a separate sawdust-pulping system is that, compared with chips, sawdust is more rapidly impregnated and cooked. In consequence, improved control of the concentration of chemicals in the digester is very important (50). Usually, controlling the input of fluid to the digester is an effective means of controlling the concentration of chemicals. With sawdust and sawmill residues a ratio of 3.5 total liquid to 1.0 oven-dry wood has been found to be most effective with respect to chemical consumption and pulp quality. Typical conditions for continuous operation are 30 to 40 minutes cooking at 150 psi steam pressure, using 16 to 18 percent active alkali as Na_2O on wood (for further details see the literature (50).

Sawdust pulp from an M&D digester will have freeness and washing characteristics which are quite similar to those of pulp from chips.

A good system for optimum pulping and processing of sawdust and sawmill residues for use in unbleached grades of paper and paperboard is shown in figure 5.10. With such a system, up to 30% sawdust/residuals pulp can be blended into the stock for unbleached grades. Where it is not critical to use maximum blends of sawdust and residuals, simpler systems can be used. Often, blending is accomplished immediately after the sawdust blowtank, with the mixture then going directly to the chip-pulp washer. This method can allow for 15 to 20 percent blends of sawdust pulp, which is about average for most unbleached papers and boards.

These results are corroborated by the work of Villenueva et al. (51) who showed that kraft pulping of sawdust residues of Phillipines mahogany logs by the conventional sulphate process yielded 49 percent pulps. Although the physical properties of the unbleached pulp were not very good, the combination of 60 percent of bleached sawdust pulp and 40 percent of bleached abaca pulp produced writing paper of good quality.

4.4.5 CONCLUSION

From the foregoing pages it can be concluded that in principle sawdust can be used for producing pulp of acceptable quality. All standard pulping methods might be used for pulping sawdust. However the conventional digester will have to be modified or even replaced, for instance by the continuous inclined digester.

Sawdust pulp can easily be blended with a longer-fibre pulp in various ratios, depending upon the desired end products, or used as a filler to produce paper grades such as unbleached paper, paper boards, liner boards, corrugated medium and numerous printing papers. Bleached sawdust pulp (10-20%) can be blended to produce a paper of good quality (52,53,46).

The choice of pulping method depends on the local tree species, the price and the availability of base chemicals for chemical pulping and energy for mechanical pulping. It should not be forgotten that sawdust is not the easiest material for pulpmaking and that successful utilization only developed at places where experience and expertise in this technology go together with good research facilities.

The latter are especially important as the applied method has to be optimized with respect to local conditions and local wood varieties.

In order to reduce transport problems (as often encountered in developing countries) it seems desirable to set up small integrated sawmill/pulpmill/papermill combinations. Environmental considerations demand a mainly mechanical pulping method.

The main conclusion must be, however, that much research must be done on local conditions and locally available woods, and that a variety of methods should be tested, first in the laboratory, later on pilot-plant scale, before a successful industry can be started.

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MISCELLANEOUS USES OF SAWDUST

tool staff

5 MISCELLANEOUS USES OF SAWDUST

This final section deals with a variety of uses of sawdust, not covered by the preceding chapters; however, as some of these are relevant for developing countries, they are described in this last chapter.

5.1. The leather industry

The larger part of the applications of sawdust in the leather industry is found in the manufacture of patent leathers and upper, mainly derived from calf and goat skins. The hides are tanned, dyed and thoroughly dried. Thereafter, they must be softened or kneaded and then stretched: the staking and tacking process. To facilitate this process, the usually dry and rather stiff hides must be moistened. Many plants dip the hides in water or pass them through a very moist chamber. Those simple methods are, however, less conducive to uniform dampening, which is possible by using sawdust (1,2).

The sawdust pile is moistened and the hides are spread on top of each other with alternate layers of the damp sawdust between them. They are left overnight, after which they are ready for the staking and tacking process. Especially for light coloured leather the sawdust must be clean, free of splinters, chips or other foreign matter, and of nonstaining species. As it is very difficult to get this particular kind of sawdust, many manufacturers try to find other methods (1).

Much less quantities of sawdust are used in oil tanning. The saw dust is saturated with oil and then spread on the flesh side of the skin. Thus oil is absorbed by the leather (1).

In the socalled beam-house operation the hides are covered with a lime solution, which makes them very slippery. In some cases the workmen cover their hands with sawdust to obtain a good grip. Dry sawdust is also used as an absorbing medium on the floors of tanning plants (1).

5.2 The fur industry

In the fur-trade, fine sawdust is used quite extensively to get the pelts into a pliable condition and to clean them. Maple seems to be in greatest demand, but oak and other (light coloured hardwood) kinds of sawdust are used in small quantities too (1,2,3).
When the skins come into the dressing plant they are hard and stiff, so the skins have to be softened and made pliable. This can be done by dipping in water. A better grade of pelts is obtained, when they are uniformly moistened through covering with damp sawdust. In this way the hair does not come off and there is no danger of the skins being oversoaked.

Sawdust is also used in the primary cleaning. The furs are put in a drum containing dry sawdust and revolved for several hours. The final cleaning must give the hair of the fur a light fluffy appearance, after the pelts have been tanned and the leather part softened. This operation is known as drum cleaning. The furs are thoroughly tossed together with the sawdust in a large wooden or galvanized iron drum. After several hours the pelts are removed into a large drum made of wire screening. By revolving this drum the sawdust falls through the screen. The sawdust polishes the hair to produce its full gloss and luster, but it also absorbs any oil or other substance which might adhere to the hair as a result of the washing and tanning process. After dyeing, the furs are given a drum cleaning with sawdust once more to bring up the luster of the hair (1).

5.3 Fuel for curing meat and fish

Very often specially selected sawdust is used for curing meat and fish. Hickory and beech sawdust were most in demand, but also maple, oak, mahagony and other hardwood sawdust is used to produce smoke (1,2,3,4,). There are many ways to burn sawdust for smoke production.

One device consists of a cone shaped receptacle with a bottom that can be closed to drop the sawdust in the burning device below. It looks like an automatic chicken feed hopper. The sawdust in the combustor is ignited and when the present material has been burned, fresh sawdust drops out of the cone (1).

Another succesful incinerator consists of a narrow metallic pan, filled with sawdust. The sawdust is slowly consumed by the heat of a gas or oil burner beneath the pan. The pan is filled at intervals by an attendant (1).

5.4. Packing medium

Sawdust is also used for packing and shipping some agricultural products. Eggs for instance were packed in sawdust to prevent breaking (3). In the 20's and 30's, sawdust was used to store grapes. The grapes were packed on and covered with dry sawdust (4% moisture content) out of which the extremely fine dust and the larger splinters were screened. The results were very good. Sawdust is an excellent medium for storage and shipment of grapes, tomatoes, avocados, and other perishable fruit and vegetables; it absorbs the moisture, keeps them dry and insulates (1). The sawdust should be soft, dry and clean; the use of smelling sawdust has to be avoided (3).

For the same reasons sawdust is used for packing and shipping of a wide variety of products like ceramics, glassware, equipment, machineries and spare-parts. For packing of metal-ware non-acid sawdust varieties are required (2).

An opposite use of sawdust is to keep the roots of ever-
greens, rhododendrons and other similar plants moistened. To
prevent drying, wet sawdust is spread around the roots, which
are wrapped in a soil-tilled burlap for storage and trans-
portation (1).

5.5 Salting glaze frosted highways

In some countries highway departments prefer sawdust to salt
for use on glaze frosted highways (3,7).

5.6 Fire extinction

Woodchips are very useful for fire-extinction, if they are
pretreated with natriumcarbonide or alum. 100 liter woodchips
are mixed with 11 kilo fine-grained natriumcarbonide or a
concentrated alumsolution (3).

5.7 Filtering

Larger woodchips from non-resinous softwood can be used for
filtering liquids from solid particles.
Woodchips, pretreated with soda, may be used for airpurifi-
cation, especially from ammonia (3).

5.8 Stuffing

Woodchips from non-resinous softwood can be used for stuffing
dolls, buffers etc. (3).

5.9 Cleaning

The use of sawdust for cleaning and drying or wetting purposes, because of its good absorbing qualities, has been discussed in the preceding chapters. But sawdust and wood-flour are also used for the production of soap or sweeping compounds. These compounds are composed chiefly of sawdust to which has been added certain antiseptic and cleaning ingredients. Certain oils absorbed in the sawdust have the property of retaining the tiny particles of dust and this cleansing property, together with the mild antiseptic influence, renders the carpet or floor clean and bright and at the same time tends to allay the dust which would be caused in ordinary sweeping. (1,5)

Sawdust mixed with Lysol- or Chinosol-solutions are used as soapsubstitute, esp. when water is lacking and hygiene is required (3).

5.10 Fire-lighters

Sawdust lighters are made by melting resin (the cheapest, darkest quality) in an iron pot, adding the requisite quantity of sawdust gradually, and thoroughly mixing it with an iron rabble. The sawdust must be thoroughly dried or the rosin will froth up considerably. The mixture is nexed spread out on a moulding bench which has been well oiled, a well greased roller being passed over the mass, thus pressing the mixture into the furrows in the bench whilst at the same time reducing it to the proper thickness. The individual fire-lighters can then be separated from one another (6).

Also, shavings are used, sprinkled with crankcase or fuel oil (7).

5.11 Bottle-stoppers

Woodshavings are wound round a short cylindrical rod of wood, both the rod and the shavings, as well as the exterior of the composite plug, being smeared with a resinous or caoutchouc cement. The rod should be of the same length as the width of the shavings, and should have a solid handle by which the stopper can be drawn from the neck of the bottle or jar. The stoppers are finally immersed for half their length in melted paraffin wax, and are then ready for use (6).

5.12 Chemically reaction substance

When nitroglycerine in dynamite explodes, more oxygen is released than is required and some of this oxygen, by burning with the wood flour, increases the explosive force (1,6). Woodflour is very fine sawdust (see chapters 3 and 4).

5.13 Substitute for bran in bread making

In France selected species of sawdust are sometimes used as a substitute for bran in bread-making (4).

5.14 Polishing

Vorreiter (3) mentions the use of fine sawdust for polishing of metalware. Especially sawdust from hardwood (oak and beech) is useful, if it is fine and dry. The sawdust should be used with felty discs, or it has to be used in tumbling drums where the metal-ware can be placed in. Metal parts are revolved, together with the sawdust, in a large drum which absorbs the solvent solution and polishes the pieces at the same time (1).
The use of sawdust with a high resin or acid content should be avoided.

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