Wood Fuel Properties and Fuel Products from Woods

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ABSTRACT

The fuel properties of wood can be summarized by ultimate and proximate analysis and determination of the high heating value. It is not valid to list these values for species since a species has not been adequately sampled and tested. Enough is known, however, to say that softwoods have a high heating value of about 9,000 Btu per pound; whereas hardwoods have a value of about 8,600 Btu per pound. These values are probably within about ±5 percent of a value expected for a specific sample. The ultimate analysis for wood is about 50 percent carbon, 6 percent hydrogen, and 44 percent oxygen on a moisture and ash-free basis. The ash content of wood is about 0.6 percent and 3 percent for bark, but the ash content of wood fuel can be higher due to dirt associated with harvesting. The sulfur and nitrogen content of wood and bark is usally less than 0.1 percent for each, but some bark may contain as much *as* 0.3 percent nitrogen. The proximate analysis of wood is about 75 to 80 percent volatile and 20 to 25 percent fixed carbon.

Wood densification is a nethod to increase the bulk density and to decrease the handling problems associated with fuel chips, sawdust, and shavings. Fuel briquettes, pellets, and fire logs are usually made without a binder from finely divided dry wood and bark. Some fire logs are molded from a mixture of about one-half wax and one-half milled dry wood.

About 850,000 tons per year *of* charcoal briquettes are produced annually from a mixture of mainly wood and bark charcoal, starch binder,

and various amounts of lignite charcoal, clay and sawdust. The charcoal is made in kilns, from logs and sawmill slabs and edgings, and in multihearth furnaces, from milled wood and bark, sawdust and shavings. Nearly all of the charcoal is used for cooking.

Wood gasifiers have Potential for providing all the fuel needs for small oil- or gas-fired boilers and supplemental fuel for large boilers. At this time, however, there is no long-term operating and maintenance experience for gasifiers Gasifiers are still in the development stage.

Pyrolysis and hydrolysis processes have potential for production of some chemicals now obtained from petroleum. At this time the processes are not proven, and they need to be demonstrated on pilot and precommercial plant scale before they can be scaled up to commercial size.

PRESENTATION

Fuel Properties of Wood

The fuel properties of wood can be summarized by ultimate and proximate analyses and determination of higher heating value. The analyses are usually determined with procedures as prescribed for coal but with some modifications. The analysis results generally vary about as much within a species as they do between species, except that softwood species generally have higher carbon content and heating values than hardwood species. This is due to the presence of more lignin and resinous materials in softwood species.

The ultimate analysis of any wood species is generally 50 percent carbon, 6 percent hydrogen, and 44 percent oxygen on a moisture- and ash-free basis. The ash content is about 0.6 percent for wood and 3 percent for bark, but the ash content of wood fuel can be higher due to dirt picked up during harvesting and storage. The sulfur and nitrogen content of wood and bark is usually less than 0.1 percent for each, but some bark may contain as much as 0.3 percent nitrogen. The range of carbon content for hardwood species is usually from 47 to 50 percent and for softwoods, from 50 to 53 percent.

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The proximate analysis of wood is 75 to 80 percent volatiles and 20 to 25 percent fixed carbon.

The higher heating value of hardwood species is usually about 8,600 Btu/lb (20,000 J/kg), and for softwoods, about 9,000 Btu/lb (21,000 J/kg). These values are within about ±5 percent of nearly all of the values reported in the literature for specific samples. A systematic study of the heating value of a species has not been done because it requires measuring the heating value at various positions in a tree from trees selected from the entire geographic range of the species. For this reason I do believe it valid to tabulate the heating value of wood by species.

The most common constituents of the ash in wood are calcium, potassium, phosphorus, magnesium and silica. Ashes recovered from burned wood are about 25 percent water soluble and the extract is highly alkaline. The ash fusion temperature is in the range of 1,300° to 1,500°C.

Since wood is usually measured by the cord, it is desirable to have some reliable estimate of the heating value of a cord. Figure I is useful for estimating this value for wood that contains no moisture. It is also helpful for comparing the relative heating value (and dollar value) of various species. For instance, it can be quickly seen from the graph that a cord of hickory can have almost twice the heating value of a cord of fir, spruce, or aspen.

The graph was constructed with the heating values above, density and specific gravity information from handbooks, and my own measure-ments of the cubic feet of solid wood in a cord. The usual estimates of solid wood in a cord are 80 to 85 cubic feet per cord, but these values are probaly appropriate for pulp-wood logs; I measured 90 to 95 cubic feet per cord for split firewood.

To use this graph with a known species, start from the right side at the species name, go across to a solid-wood-per-cord line, and then down to read the Btu-per-cord value. If the wood is split and tightly piled, I suggest using the 95 cubic-foot-per-cord line. If the species is not shown, choose one that has a similar density or locate a representative density value from a handbook that gives the physical properties of wood species. If the density or specific gravity can be estimated, start at the left and go across to the appro-priate solid-wood-per-cord line and read the Btu's per cord at the bottom.

By using the graph, it can be estimated that the heating value of maple and yellow birch, which have a density of 32 to 34 pounds per cubic foot, is 26 to 28 millin Btu's per cord containing 95 cubic feet of dry wood. If the wood is air dry, about 50 percent of the heating value can be recovered with a modern wood-burning appliance.

The moisture content of freshly cut wood varies between species and also between portions of the tree. Between species it can range from 30 to 70 percent. More commonly, it is 45 to 50 percent. Within a tree, the heartwood generally has lower moisture content than the sapwood. For hardwood species this difference is usually small, but for softwood species such as Douglas-fir, the difference can be as great as 30 percent for heartwood compared to 50 percent for sapwood.

The combustion of wood is preceded by evaporation of the moisture and distillation and burning of the volatiles before the fixed carbon burns. The evaporation of the moisture absorbs heat. At temperatures below 500°F, distillation of the volatile matter also absorbs heat. Beyond 540°F, exothermic reaction takes place and the distillation of the volatile matter continues with the evolution of some heat, even if no additional air is supplied. In small pieces of wood, such as sawdust, the different phases of burning occur in rapid succession. With large chunks of wood, the processes are overlapping because wood is a very poor conductor of heat. To get complete combustion of the volatile gases formed, it is necessary to supply about 80 percent of the total air required close to the surface of the fuel bed where it can readily mix with the volatilized gases. Since these gases do not ignite below 1,100°F, it is best to burn dry wood in order to obtain a higher maximum temperature.

Unburned volatiles resulting from incomplete combustion of wood can cause a large loss in efficiency. These volatiles are also a source of trouble in stoves and furnaces because of the creosote, tarry substances, and acetic they contain. To burn these volatiles, sufficient air must be supplied around or over the fuel bed. This air must be mixed with the volatiles while they are still hotter than 1,100°F and have not come in contact with cooling surfaces. Theoretically, it takes six pounds of air to burn one pound of oven-dried wood, but actually more air is required because the air and volatiles are not thoroughly mixed.

The major fractions of wood such as hemi-cellulose, cellulose, lignin, extractives, and charcoal have different heating values, and some have been reported in the literature. The heat-ing value of chemically isolated hemicellulose and cellulose have been measured to be about 8,000 Btu per pound. The heating value of various lignins range from 10,000 to 11,000 Btu per pound. The resinous material from softwood species has a heating value of about 16,000 Btu per pound. Charcoal formed after most of the volatiles have been distilled off has a heating value of about 12,000 Btu per pound.

Processes to Make Fuel Products From Wood

Densification

The purpose of densifying wood is to increase the bulk density and to decrease handling problems associated with fuel chips, sawdust and shavings.

In the 1930's, pres-to-logs were produced from dry plywood and sawmill residue in the West. Since then, a few other types of briquetting machines have been used to make wood briquets. The briquets have been In the form of 4-inch-diameter logs or disks, 1-inch (and smaller) diameter pellets and 1-inch cubes. These are usually made without a binder except, at present, the most popular fireplace firelog is made with wax. These logs usually contain at least 50 percent wax by weight.

Figures 2 and 3 show the two most common ways to make fuel pellets today. Figure 2 shows a pres-to-log type briquetter that can make 4-inch-diameter firelogs or smaller diameter pellets depending on the diameter of the exit die. Figure 3 shows a pellet mill of the type now used to make fuel pellets. This mill was designed to pelletize animal feed.

Figure 4 shows a schematic layout of a wood pelletizing plant such as would be required for using green chips, sawbark or bark. The source can be a wood-fueled furnace making hot air or steam. The dryers are usually heated by hot air or combution gases. The wood is often heated directly with low-pressure steam in the screw conveyor just prior to compression through the pellet mill dies. The moist heating softens the wood particles and reduces the electrical energy needed to drive the mill. Host of the condensed steam evaporates from the pellets before they get to the storage bins.

Recently constructed pellet mills have the capacity of about 300 tons of product per day. Total cost of the plant is about $2 million.

Charcoal

Charcoal is produced by heating wood at conditions that severely restrict the amount of oxygen. When wood is heated slowly to about 280°C, an exothermic reaction occurs. The usual carbonization procedure is prolonged, heating to a final temperature of 400° to 500°C in the absence of air. The term charcoal also includes charcoal made from bark.

Charcoal is produced commercially in either kilns or continuous furnaces from primary wood Processing residues and from low-quality round-wood. A kiln is used if the raw material is in the form of roundwood, sawmill slabs or edgings. The most common kilns in the United States are constructed of poured concrete. They have a capacity of 40 to 100 cords of wood and oerpate on about a 7- to 12-day cycle. If the raw material is in the form of sawdust, shavings or milled wood and bark, it is converted to charcoal in a continuous multiple-hearth furnace commonly referred to as a Herreshoff furnace. The capacity is usually at least one ton of charcoal per hour. The yield of charcoal is about 25 percent by weight on a dry basis.

The proximate analysis of charcoal is about 20 to 25 percent volatile matter, 70 to 75 percent fixed carbon, and 5 percent ash. The higher heating value is about 12,000 Btu/lb (28,000 J/kg). Charcoal briquets have a higher heating value of only about 10,000 to 11,000 Btu/lb (23,000 to 25,000 J/kg) due to added ingredients.

To alleviate the air pollution problem associated with charcoal kilns and furnaces, the gases from the kilns and furnaces are burned. The gases can be burned with additional fossil fuel to recover heat and steam, or they can be burned in afterburners to nearly eliminate visible air pollution and odors.

Charcoal was an important industrial raw material in the United States for iron ore reduction until it was replaced by coal in the early 1880's. Charcoal production did continue to increase, however, due to the demand for the byproducts--acetic acid. methanol and acetone. In 1920, nearly 100 byproduct recovery plants were in operation in the United States, and in 1969 the last plant ceased operation.

Charcoal production decreased from 500,000 tons in 1909 to about 210,000 tons in 1947. Following this, production increased to 265,000 tons in 1956, to 500,000 tons in 1968, and to over 800,000 tons in 1980. The latter two production figures are for production of charcoal briquets that, in addition to charcoal, contain a starch binder and also can contain clay, coal dust, sawdust and char from nut shells and lignite.

The increase in production since the 1940's reflects the us of charcoal briquets for home recreational cooking. The charcoal presently produced is nearly all consumed for cooking as charcoal briquets. Some charcoal is used in certain metallurgical and filtration processes and horticultural uses. In Brazil, charcoal is produced in beehive-type kilns from naturally and plantation-grown trees for use as an iron ore reducing agent because Brazil does not have abundant supplies of coking coal. In many developing countries, charcoal is the preferred fuel for domestic cooking. Often it is made in pit-type kilns, but beehive and portable sheet metal kilns are also used where the construction materials are available.

Gasification

Wood gasifiers have potential for providing all fuel needs for small oil- or gas-fired boilers and supplemental fuel for large boilers. At this time, there is no long-term operating or maintenance experience.

At least three companies have stationary-bed gasifiers in operation on a fairly large

scale. These are manufactured by Westwood Polgas and Omnifuel in Canada and Applied Engineering In North Carolina. Wright Malta in New York is developing horizontal moving bed demonstration unit.

In a gasifier, the wood is heated and partially combusted to form combustible gas containing carbon monoxide and hydrogen. This hot gas which also contains water vapor, carbon dioxide, nitrogen, particulate materials, and vapors of creosote, is then admitted to a furnace along with more combustion air where it is burned. A pilot flame from gas or oil is usually required to prevent a flameout. The inert gases reduce the heating value while the particulate and condensable gases cause buildup in the gas transfer pipe and wood-gas nozzle. Figure 5 shows a schematic view of the wood gasification system at Rome, Georgia. This system is designed to use green mill residue and whole tree chips.

Gasifiers have also been used to produce fuel for internal combustion engines. When fuel supplies were low during World War II, gasogens were used on many vehicles in all parts of the world. They were usually fueled with charcoal because it contained less water, hydrogen and volatiles than wood. Charcoal provided a more uniform fuel and minimized the gas cleanup problems.

Figure 6 is a 1942 photo of a 1936 Ford truck outfitted with a gasogen. The gasogen was built and tested at Forest Products Laboratory. Its use provided the truck with one-half the power obtained when operating with gasoline.

These types of gasifiers have application for stationary internal combustion engines to turn electric generators in remote areas and developing countries where wood is available. As with the other gasifiers, there is no current long-term operating experience.

The production of methanol from wood requires a dependable wood gasification process to produce syn-gas (carbon monoxide and hydrogen). The syn-gas can then be reacted to form methanol production from natural gas. A proposed methanol-from-wood scheme is shown in Figure 7.

Pyrolysis

Wood pyrolysis refers to heating wood to produce a combustible gas, a liquid fuel and charcoal. Several processes are now under development. They differ mostly in the method and rate of heating, and this influences the yields of the three products. Rapid heating (in the range of seconds) to high temperature increases the yields of lower molecular weight liquids and gases and lowers the charcoal yield. Slow heating (hours) leads to lower gas yields, higher molecular weight liquid and higher charcoal yields. Current research on wood pyrolysis is to study the effects of different ways and rates to heat wood and measure the effects on the product yields. Some research

is also looking at catalysts to increase the yield of liquid fuels at lower temperatures.

During charcoal manufacture with retort processes, the noncondensible and condensible gases can be collected and used for fuel. At some charcoal plants all of the gases are burned for heat recovery. Condensable gas forms a liquid containing water, a vast array of chemicals and tars. The liquid is acidic and, even if the water is removed, it has only about one-half the heating value of fuel oil.

Acid Hydrolysis

Wood hydrolysis plants were operating at Georgetown, South Carolina and Fullerton, Louisiana, during World War II to produce industrial ethanol. The raw material was southern pine mill residues, and the yield was about 20 gallons of ethanol per ton of wood. These plants closed when residue was not available after the sawmills closed. During World War II the Government constructed a plant at Springfield, Oregon. It never operated successfully. The plant was adapted to use the Madison process that was developed at Forest Products Laboratory.

A number of wood hydrolysis processes have been developed to hydrolyze the hemicellulose and cellulose to sugars. The most common method is to hydrolyze with about 0.7 percent sulfuric acid at temperatures of 140° to 190°C. The hydrolysate containing the sugars, acid and numrous, usually undesirable, byproducts is then separated from the unhydrolyzed lignin and cellulose and neutralized. Nutrients and yeast are then added, and most of the sugars can be fermented. Most often the end product has been ethanol, but other fermentation products are possible. The lignin residue is chemically inert, but it is useful as a fuel.

The amount of hemicellulose and cellulose in wood and the chemical products desired determine the general type of process that might be used to hydrolyze wood. Hardwoods yield more five-carbon sugars than softwoods. Since, at this time, only the six-carbon sugars from cellulose are readily fermentable, softwoods are desired for ethanol production, but they are not as widely available as hardwoods. Hardwoods are more widely available now, so considerable effort has been expended to develop processes to utilize their unique constituents.

Figure 1 in Forest Products Laboratory Research Paper FPL 385 shows the Madison Process as it was described in the 1940's. This process was developed to hydrolyze softwood species. The hemicellulose sugars were recovered in the form of furfural, and only one stage was required. If hardwood species are used, a two-stage process is more desirable to maximize the recovery of both the hemicellulose and cellulose (fig. 8). High yields of hemicellulose products can be obtained at the milder prehydrolysis conditions compared to the higher temperature required to maximize glucose yields from the cellulose in the second stage.

The several acid hydrolyses processes now being promoted to produce ethanol from wood, but they do it in different types of equipment at slightly different acid-temperature-time conditions. The stake process uses a horizontal screw reactor. The Iotech process uses a high-pressure, short-time hydrolysis followed by rapid release of pressure. The twin-screw-extruder process developed by New York University uses a high-pressure, special reactor design. The plug-flow reactor under study at Dartmouth and another developed by American Can use different methods to pump the wood and acid into the reactor. The New Zealand process under license to Ultra Systems is probably a modern version of Madison Process. After the hydrolysis of the cellulose, the processes could be identical if the same products were to be recovered.

Some of the two-stage processes differ in that the residue from the first-stage is delignified with a lignin solvent. This dissolves the lignin to leave only cellulose to be hydrolyzed in the second stage. The lignin is then recovered by distilling off the solvent. This is in contrast to hydrolyzing the firststage residue to solubilize the cellulose and leave the lignin.
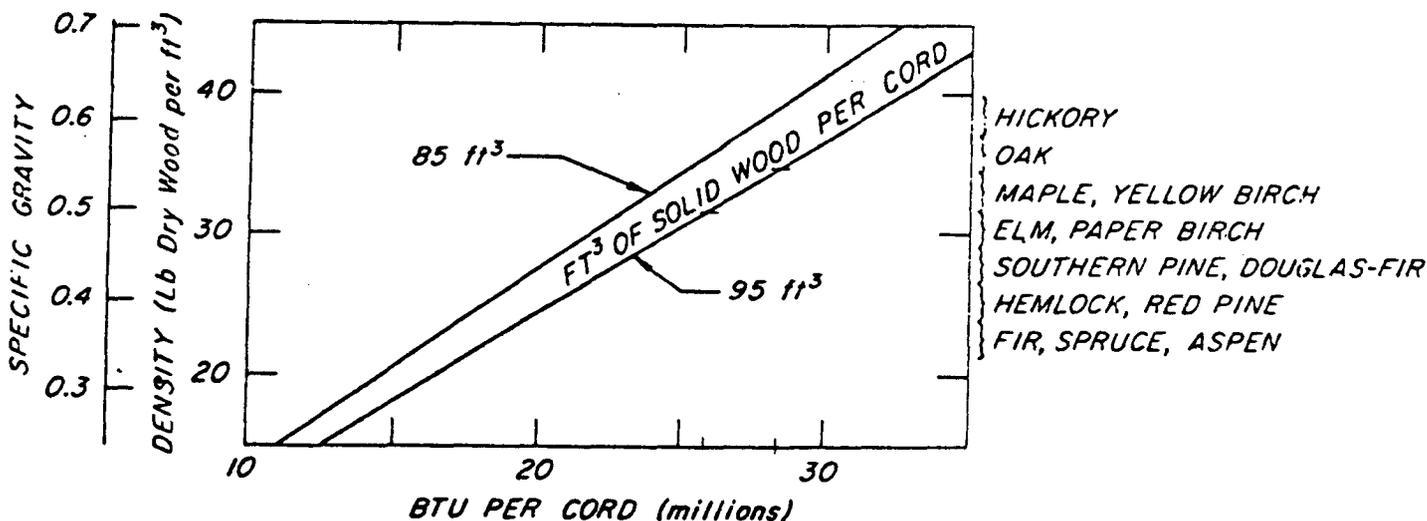
HIGHER HEATING VALUE PER CORD OF WOOD

Figure 1.--Graph to estimate the higher heating value of a cord of wood knowing either species, specific gravity, or density. Higher heating value is defined as the theoretical amount of heat obtainable from 1 cord of wood containing no moisture. The actual heat obtainable will be about 60 percent of this estimate if air-dried wood is burned in a well-designed wood burner.
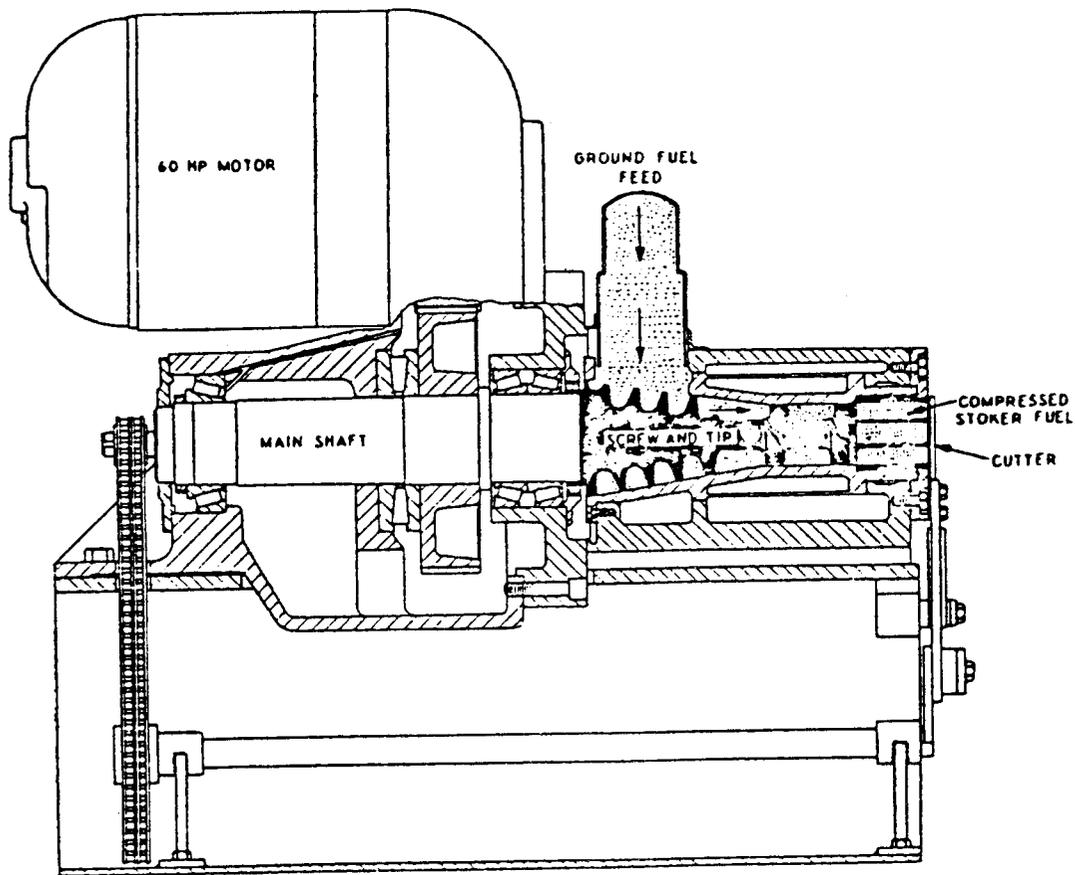
(M 151 664)

18

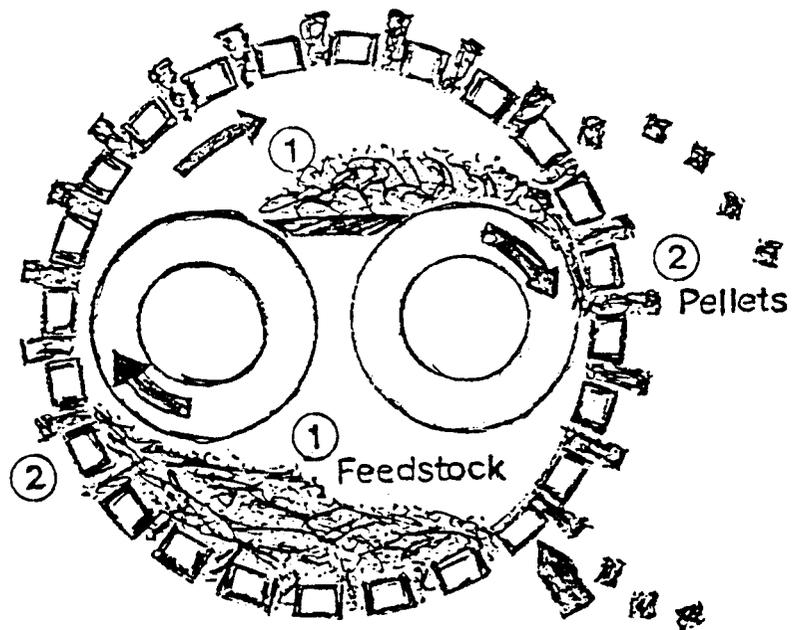Figure 2. --Pres-to-Log stoker-fuel machine.
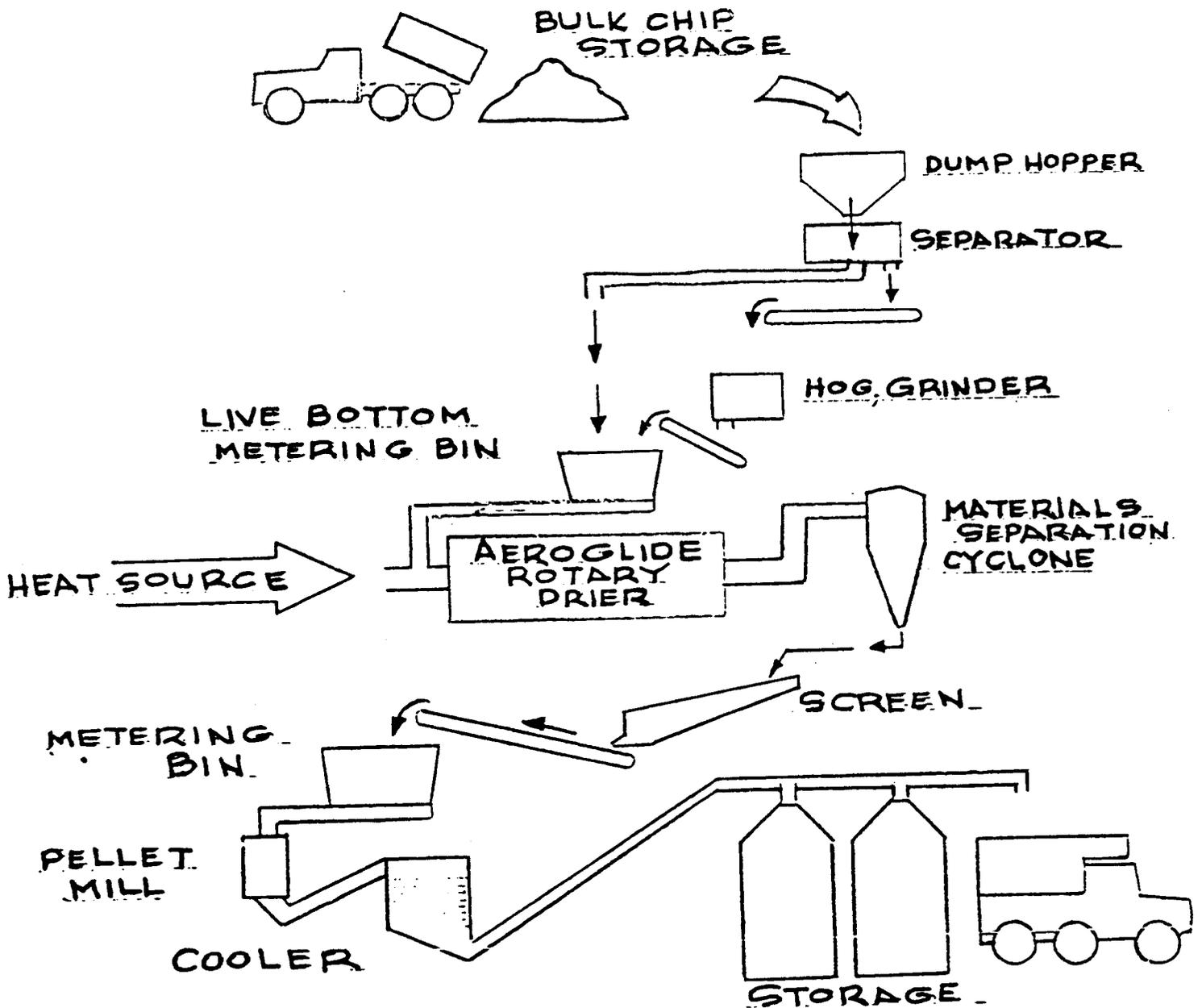

Figure 3. --Pelleting process.

WOOD ENERGY CENTER

BULK CHIP STORAGE

DUMP HOPPER

SEPARATOR

HOG GRINDER

LIVE BOTTOM METERING BIN

HEAT SOURCE

AEROGLIDE ROTARY DRIER

MATERIALS SEPARATION CYCLONE

SCREEN

METERING BIN

PELLET MILL

COOLER

STORAGE

Figure 4

WOOD GASIFICATION SYSTEM
NORTHWEST REGIONAL HOSPITAL
ROME, GEORGIA

WOOD CHIP DELIVERY

LIVE BOTTOM HOPPER

LOADING CONVEYOR

WOOD STORAGE
(3.5 DAYS)

EXISTING 19,000 LB/HR
GAS/OIL PACKAGE BOILER

LOW BTU
GAS PIPE

LOW BTU
BURNER

25 MILLION
BTU/HR
GASIFIER

RECLAIM
CONVEYOR

COMBUSTION
AIR SUPPLY
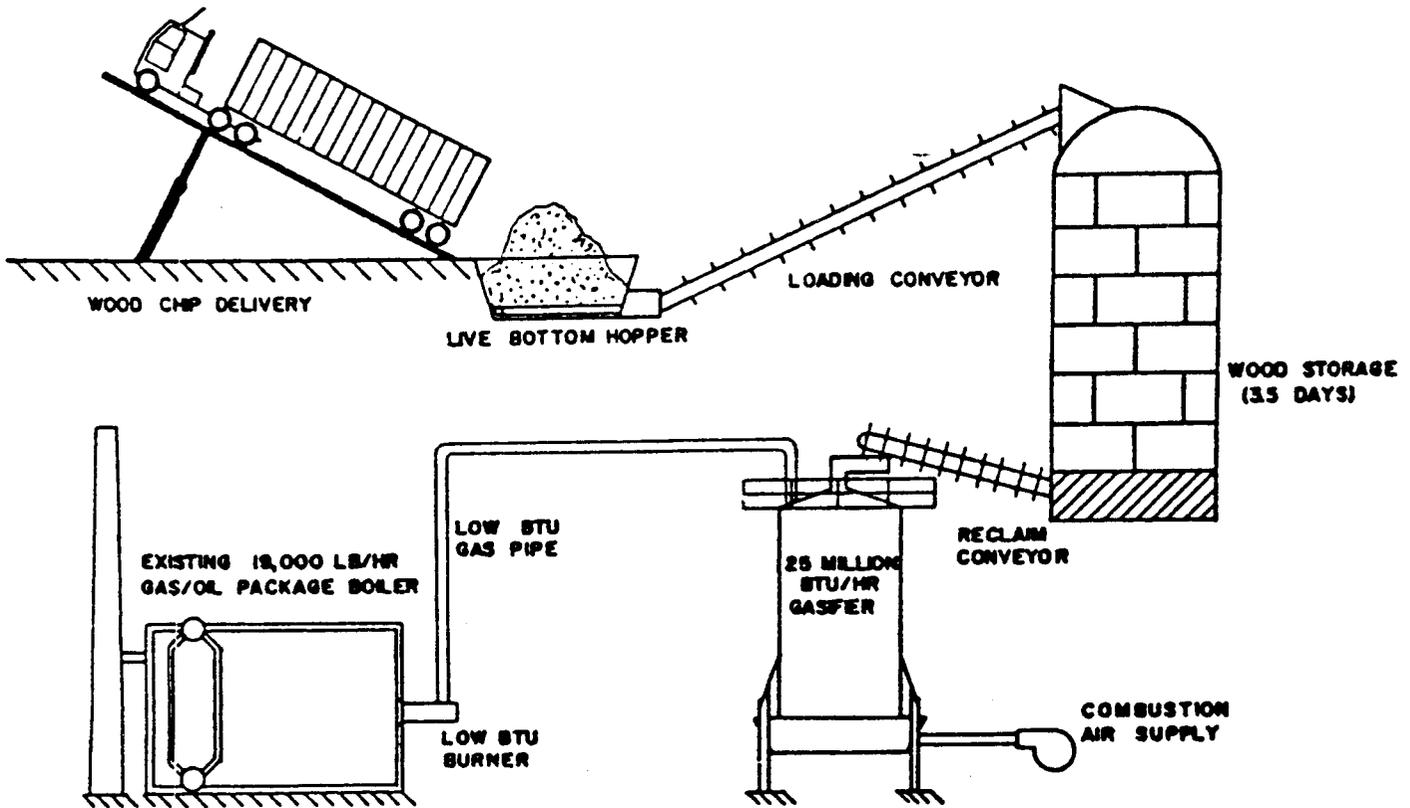
Figure 5.--Wood gasification system at Northwest Regional Hospital in Rome, Ga.

21

PRODUCER

COOLERS

CYCLONE

FILTER

FELT

COTTON WASTE

SISAL FIBRE

GAS

AIR

DUST

CLEANING DOORS

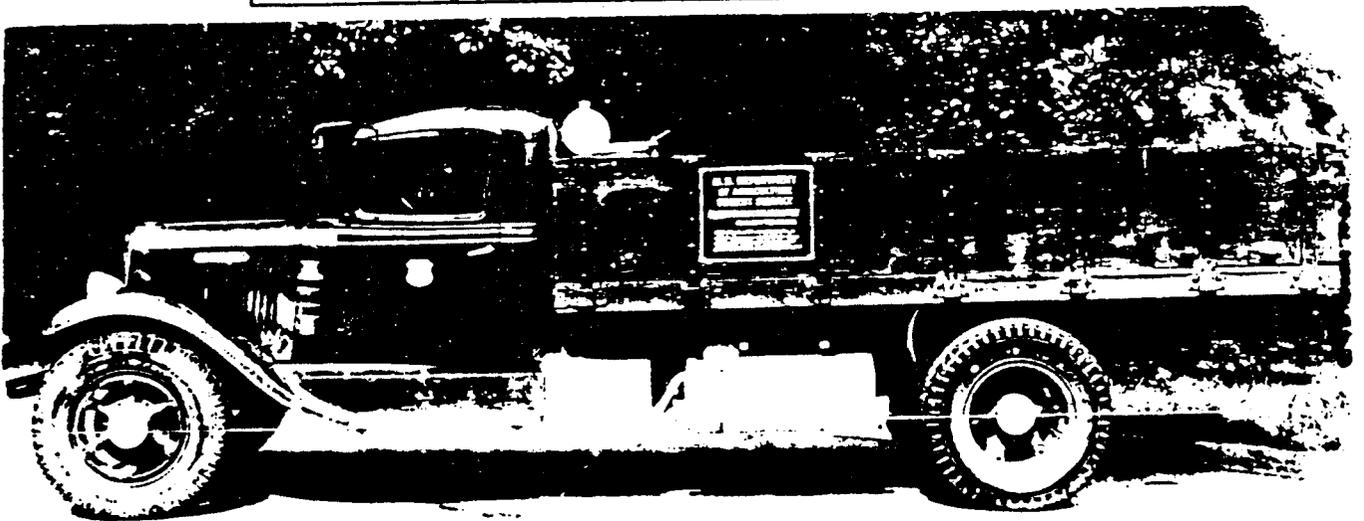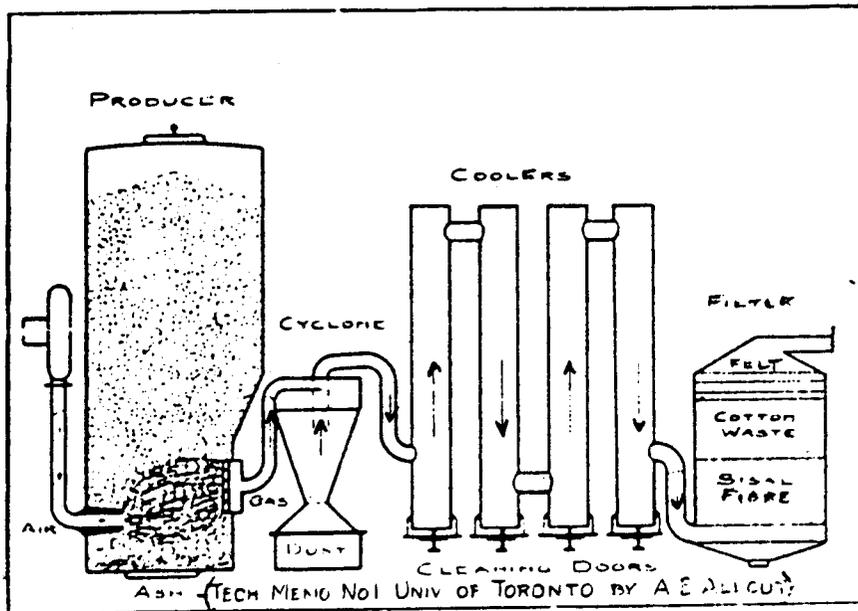ASH (TECH MEMO NO1 UNIV OF TORONTO BY A.E. ALLCUT)

Figure 6.--Gasogen mounted on FPL truck--1942.

Process Steps

1. Partial oxidation of wood waste.

2. Clean and cool crude gas.

3. Compress to 100 psig.

4. Remove carbon dioxide.

5. Remove residual carbon dioxide.

6. Remove nitrogen and hydrocarbons.

7. Compress to 400 psig.

8. Shift gas to two parts hydrogen and one part carbon monoxide.

9. Remove carbon dioxide formed in shift.

10. Compress to 2500 psig.

11. Convert hydrogen and carbon monoxide into methanol.

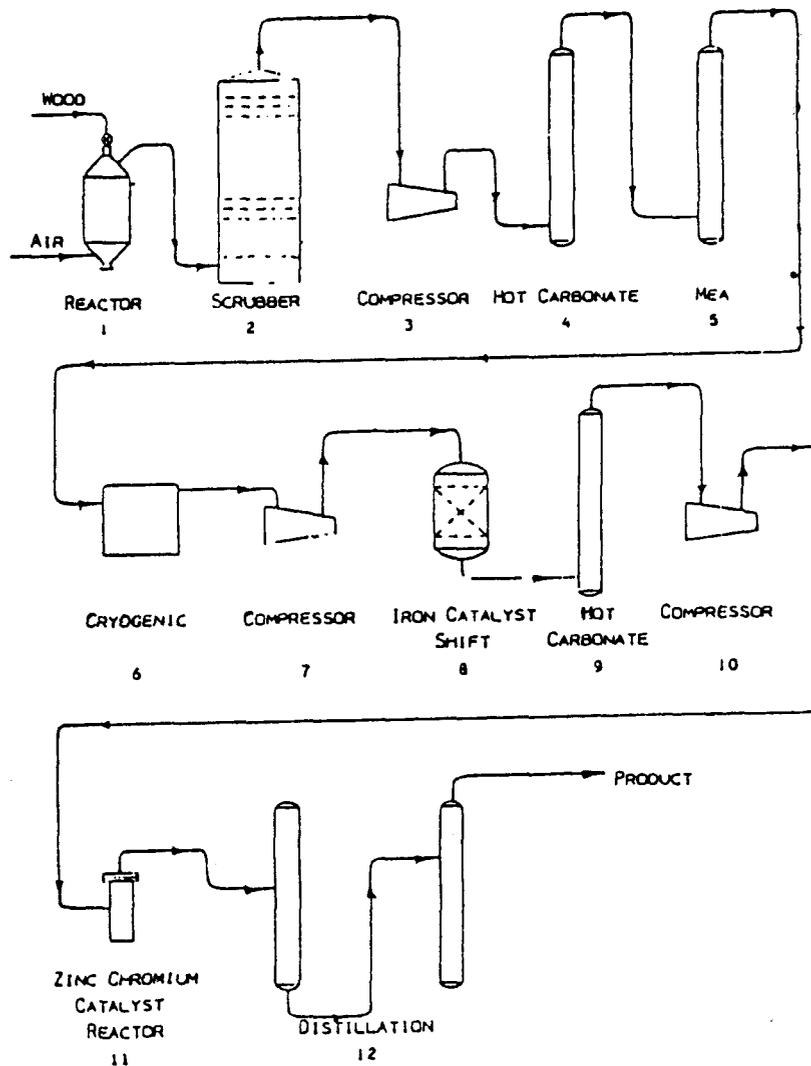12. Refine crude methanol into specification grade product.

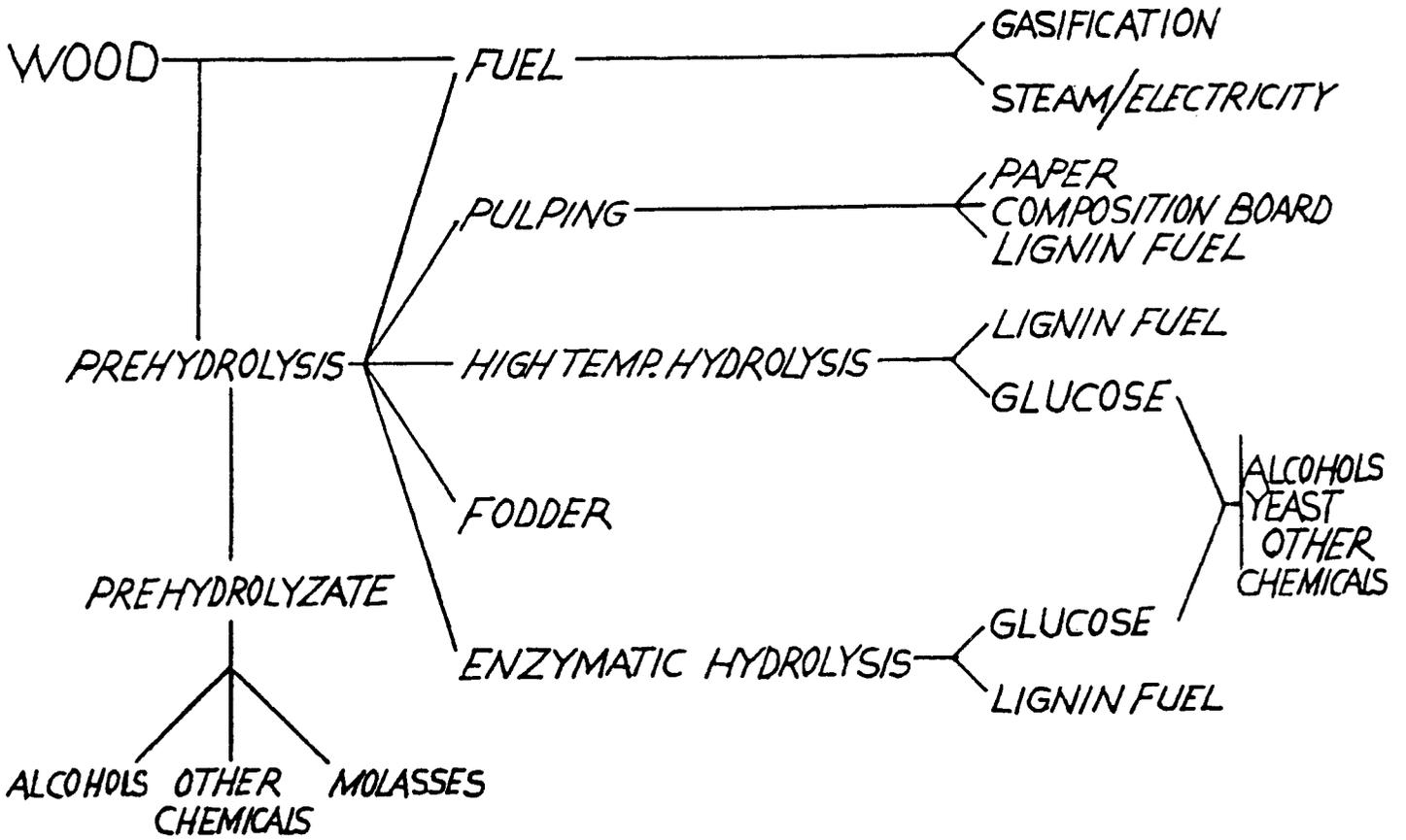Figure 7.--Methanol synthesis from wood waste.

PROCESS ALTERNATIVES

WOOD

FUEL
- GASIFICATION
- STEAM/ELECTRICITY

PULPING
- PAPER
- COMPOSITION BOARD
- LIGNIN FUEL

PREHYDROLYSIS

HIGH TEMP. HYDROLYSIS
- LIGNIN FUEL
- GLUCOSE
  - ALCOHOLS
  - YEAST
  - OTHER CHEMICALS

FODDER

ENZYMATIC HYDROLYSIS
- GLUCOSE
- LIGNIN FUEL

PREHYDROLYZATE
- ALCOHOLS
- OTHER CHEMICALS
- MOLASSES

Figure 8.--Process alternatives

24

WOOD

PRE-TREATMENT
REACTOR

STIR

RECYCLE
ENZYME
AND
UNREACTED
CELLULOSE

pH 4.8   CELLULOSE 30%

50 °C   ENZYME 0.1%

REACTOR

FILTER

ENZYME (Broth)

STIR

FERMENTER

TRICHODERMA
VIRIDE
MUTANT

GLUCOSE
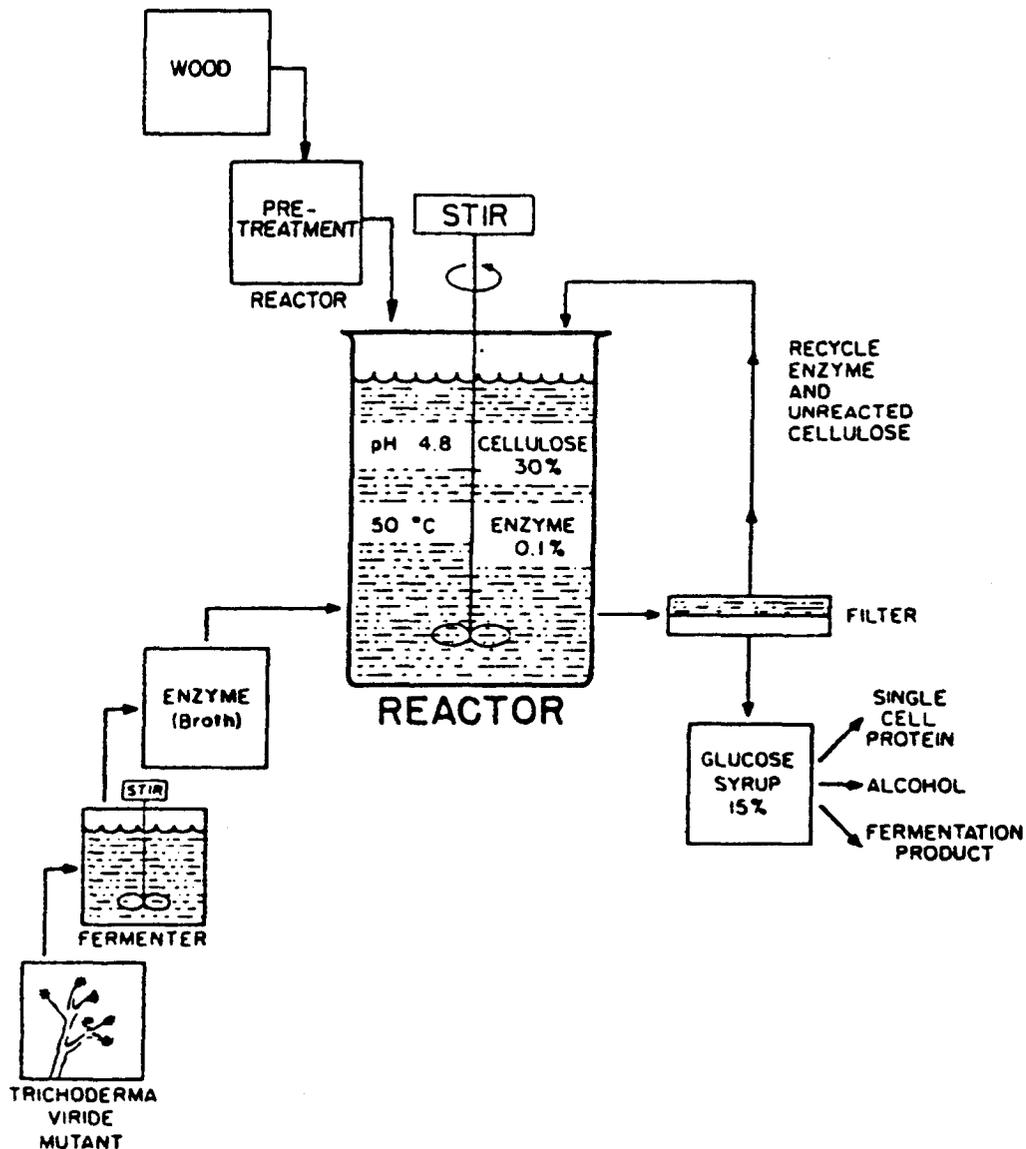SYRUP
15%

SINGLE
CELL
PROTEIN

ALCOHOL

FERMENTATION
PRODUCT

Figure 9.--General enzymatic hydrolysis process.

(M 149 777)

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25