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WOOD - THE RENEWABLE FUEL

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20. ABSTRACT (Continued)

Current logging practice leaves about 27 x 10^7 cubic meters (9.5 billion cubic feet) of wood waste in the forests. This is augmented by wastes generated by forest management techniques, removal of cull or non-commercial trees, and natural disasters (fire, disease, insects, hurricanes). This wood could provide industry with a constantly renewable, low sulfur and ash content fuel which would also reduce air pollution emissions.

Thus, wood wastes are currently available and will continue to be. They are already being used to some extent by wood processing industries that use direct combustion and pyrolysis for converting the wood into energy. However, their use by other industries is somewhat dependent on the potential user's proximity to the waste reservoir. The use of wood as a prime energy source is currently being investigated by the U.S. Army and NASA for application at the National Space Technology Laboratories and the Mississippi Army Ammunition Plant located in southwestern Mississippi.

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INTRODUCTION

As new, low cost, domestic sources of oil and gas become more difficult to find, imports begin to increase substantially. This trend has been accelerated by subsidies for overseas developments and air pollution regulations which make the use of coal more difficult. The problem (relying on outside sources) became evident to knowledgeable observers in 1971 and 1972 when the Organization of Petroleum Exporting Countries (OPEC) increased crude oil prices. The embargo in October 1973 made the general public aware of the severity of the problem.

The sharp increase in fossil fuel prices in 1973-74 was a warning of the likely effect on the world economy of an oil and gas shortage. Increasingly larger supplies of energy are needed to maintain a basic standard of living and sustain economic growth, but gas and oil reserves are dwindling and there are major problems associated with increasing coal use. These previously abundant fossil fuels cannot continue to meet the nation's energy needs. As prices rise and sources of fossil fuels dwindle, fuel substitutes which have not been commercially attractive in the past are generating new interest and other sources of fuel are being investigated. Among the most promising is one which is renewable, has low sulfur and ash content, and reduces air pollution emissions; this fuel is wood.

Use of the large volume of urban and forest wood residues generated each year could significantly reduce the United States' dependence on fossil fuels. Current logging practices annually leave about 27×10^7 meters^3 (9.5 billion cubic feet) of fibre in the forests and primary and secondary manufacturing wood plants generate 3.7×10^7 meters^3 (1.3 billion cubic feet) of wastes each year (ref. 1). Obviously all these wood residues cannot be made available to the consumer market. Some wastes are in inaccessible areas; others would be too costly to recover. However, vast amounts of forest residues are available and, in recent years, there has been increased incentive towards recovery technology. To improve harvesting efficiency and use, the logging industry has been developing large mechanized systems, some of which are designed to harvest whole trees. The trees are sheared at ground level, placed in bundles, and transported to equipment which can chip a whole tree mechanically, eliminating much tedious and time consuming work which was previously done by hand.

The wood processing industry is a prime alternate energy source. Tremendous quantities of timber are harvested for processing into lumber, plywood, or pulp and large volumes of wood and bark residues are generated in the harvesting and processing operations. Yields of 0.675 - 1.35 kg/m^2/year (3-6 tons/acre/year) have been achieved on tree farms in the Southeast, and mechanical methods of cultivating and harvesting, similar to conventional agriculture, can be used if trees are planted in rows and harvested young (ref. 2). Of the 0.675-1.35 kg/m, approximately 20% is in the crown and limbs, and an additional 18-20% is in the stump and roots. Use of the stump and roots is presently limited by the technology involved in removing them from the ground. On the other hand, the practice of coppicing can take advantage of energy stored in the tree roots and extend the interval between plantings. Coppicing involves cutting a tree that is a few years old, allowing the stump to sprout for a few years, then harvesting the sprouts. The same stump can be allowed to sprout several times, lessening the need for replanting.

The debris remaining after logging operations includes deadwood, culls, logs, branches, and brush. At present this waste is either left where it falls, stacked, and burned at the site, or chipped for faster decay. These disposal methods are potential fire hazards. It is estimated that for each board foot (12 x 12 x 1 in.) of harvested logs, there are 0.9 kg (two pounds) waste debris, about half of which is organic matter.

Additional sources of wood could be generated by correct forestry management techniques, such as removing cull or non-commercial trees and wood waste left by natural disasters (i.e., fire, disease, insects, hurricanes). The removal of the undesirable trees would free valuable land space and conserve soil nutrients and water. Undesirable trees should be replaced with better quality trees which would be maintained in the appropriate harvesting cycle. Like all crops, timber must be properly managed to get maximum production. Trees must have the right amount of space to grow properly; for example, if the stand is too thin, the trees tend to grow outward instead of upward, if it is too crowded they will slow in growth and possibly stop growing altogether. It is, therefore, imperative that correct forestry management techniques be pursued to obtain optimum forest yields.

DISCUSSION

The combustion of wood waste produces less air pollution than either coal or oil, and the ash residue (charcoal) is highly combustible. Further, the cost of energy per 1.06 x 10^9 J (million (MM) BTU's) can be less for wood waste than for fossil fuels. Since the cost of wood is directly related to transportation distance, the actual cost for any specific application can vary considerably. The figures below give the comparative energy costs, based on mid-1975 prices, of fossil fuels and wood species indigenous to Vermont:

COMPARATIVE ENERGY COSTS (ref. 2)

Type	Market price	Assumed conversion efficiency (%)	Cost \$/1.06 x 10^9 J (\$/MMBTU)
No. 2 fuel oil	\$ .38/gal (\$99.6/m^3)	70	3.87
Coal	\$50.00/ton (\$.055/kg)	65	2.84
Natural gas	\$ 1.50/KCF (\$.053/m^3)	80	1.87
Hardwood	\$30.00/cord (\$.013/kg)	60	1.68

Prices for wood varied from \$1.40 to \$2.81/1.06 x 10^9 J depending on the type and location of the wood waste.

Wood has several advantages. It is renewable, has a low sulfur and ash content, generates less air pollution, and for many applications, is available locally. The primary disadvantages of wood are its bulkiness, non-uniform moisture content, potential fire hazard in storage, matting and packing of chips in storage, and dust problems.

The basic composition of most wood and bark species is relatively constant. Unlike most crude oils and coals, bark and wood fuels have negligible surfur content and thereby reduce sulfur oxide (SO_x) air pollution problems. Air pollution problems caused by ash are also relatively low. The ash is the noncombusted portion of the fuel, which is normally separated from the combustion gases before passing out the stack. The wood ash content is less than one percent by dry weight, but the noncombustible fraction of the wood waste is often increased by dirt and sand adhering to the bark during harvesting and handling.

The most important property of wood is its heating value. Most wood species, when bone dry, exhibit a Joule (BTU) content of approximately 19 x 10^6 J/kg (8300 BTU's per pound). Bark, because of its high resin content, generally has a higher heating value than wood. The mositure content of dry wood is also an important property in considering the use of wood waste as a fuel (table 1). The heat required to evaporate the water is lost to the rising vapors. Therefore, moisture adds a negative heating value to the wood.

The combustion of wood waste involves the occurrence of three phenomena:

1. The water is driven off.

2. The volatile hydrocarbons are evolved and mixed with oxygen, giving off heat, by combustion, and

3. More heat is produced as a result of the oxidation of the fixed carbon at high temperatures.

The amount of air required to combust the carbon and hydrogen in the wood waste completely to carbon dioxide and water is the stoichiometric air. Approximately 6.5 units of air are required to completely burn one unit of wood (A/F = 6.5).

Unfortunately, there are a number of problems involved with using wood waste. Most important is the cost of collecting, transporting, and preparing the waste. A considerable effort has been exerted to reduce these costs in the field of municipal waste, which has the added benefit of "tipping fees" to help offset the recovery process economics.

Wood waste has its advantages, also. The homogeneous, lignocellulosic characteristics of wood waste preclude the necessity for expensive resource recovery equipment before processing. (Resource recovery has not yet proven economical in municipal waste applications due to poor markets for glass and iron scrap.) Another advantage of wood waste is that the combustion products from these wastes have an extremely low

Table 1. Relationship of bark moisture to heat content

Moisture (%)	BTU per lb	MJ per kg
0	8750	20.4
20	7000	16.3
40	5250	12.2
50	4375	10.2
60	3500	8.1
70	2625	6.1
80	1750	4.1
90	875	2.1

sulfur content, which alleviates concern over impacting the SO_x problem. This characteristic lends itself to combining wood waste with various high sulfur fuels to reduce the total sulfur oxide (SO_x) emissions.

To use wood waste economically, the problem of overcoming transportation costs must be solved. This problem would not be as grave if the heating value of the raw fuel were higher. Unfortunately, wood waste is bulky and typically contains 50% water. In addition, new burners, furnaces, and pollution abatement facilities must be built or old units modified to accommodate the wood waste itself (direct combustion) or the burning of pyrolytic products (oil, gas, or char). Many incinerators use excess air to achieve maximum combustion efficiency and reduce HC, CO, and NO_x emission levels.

Many wood waste applications generate steam as the final product. To accomplish this, the following equipment is required:

- mill or hog grinder to reduce wood waste to chip form
- dryer to remove moisture from the wood
- storage facilities to maintain steady feed
- materials handling equipment (i.e., loaders, conveyors)
- furnace/incinerator for wood combustion
- boiler for steam generation
- pollution abatement measures
- ash removal

Several factors must be considered when choosing a system for using wood waste. Handling of the wood and ash should be kept to a minimum. The combustion system requires a feed mechanism which does not jam and which provides adequate air for the combustion process. The main chamber must be sized to provide maximum combustion efficiency and designed for easy cleanout of slag residues. In order to be energy efficient, proper use of heat exchanger equipment is mandated.

Generally, in the generation of steam, efficiencies of 45 to 63% can be achieved using wood waste as feedstock. In most cases, efficiency can be increased by pre-drying the wood waste. In sizing a boiler, the assumption can be made that 5 pounds of steam can be generated for each dry pound of wood waste (ref. 1). The moisture of the wood waste plays a vital role in the process efficiency (table 1). If the moisture is greater than 15%, the efficiency of the boiler is diminished. It is, therefore, necessary to have a dryer process before the combustion phase.

Another area of concern when combusting wood waste is the visible plume and EPA particulate emission regulations. Depending upon geographic location, local municipal regulations can further restrict the particulate emission standard. Normal particulate emissions generated by wood waste furnaces range from 0.5 to 5.0 grains per standard cubic foot (ref. 1).

Direct Combustion Systems

The Combustion Power Co. Inc. is using a fluidized bed combustor (FBC) for the direct combustion of wood waste. The combustion gases drive a gas turbine. After passing through the turbine, the hot exhaust gases are passed through a waste heat boiler (ref. 3). The York-Shipley Company manufactures a heat recovery system which uses a wood waste fluidized bed (fig. 1). Hogged wood waste with moisture up to 55% can be burned. After initial start-up, the wood combustion process is self-sustaining, requiring no supplemental fuel. This fluidized bed unit (boiler) improves boiler efficiencies to the point where they are comparable to conventional fuel equipment.

In the direct combustion of wood, there are several problems which must be overcome in order to maintain an efficient operating system. The first is the moisture. Systems like the Combustion Power FBC can handle moistures up to 55% due to process design, but most of the systems require pre-drying of the feedstock which often severely reduces the overall energy efficiency of the system. The second problem is air pollution. Direct combustion often requires excess air to achieve maximum efficiency, and this can create particulate emission problems. To comply with emissions standards, it is often necessary to use both primary and secondary dust collectors and/or an electrostatic precipitator (ESP). Finally, there must be a demand for the form of energy generated, and the cost of obtaining wood feedstock must be kept to a minimum.

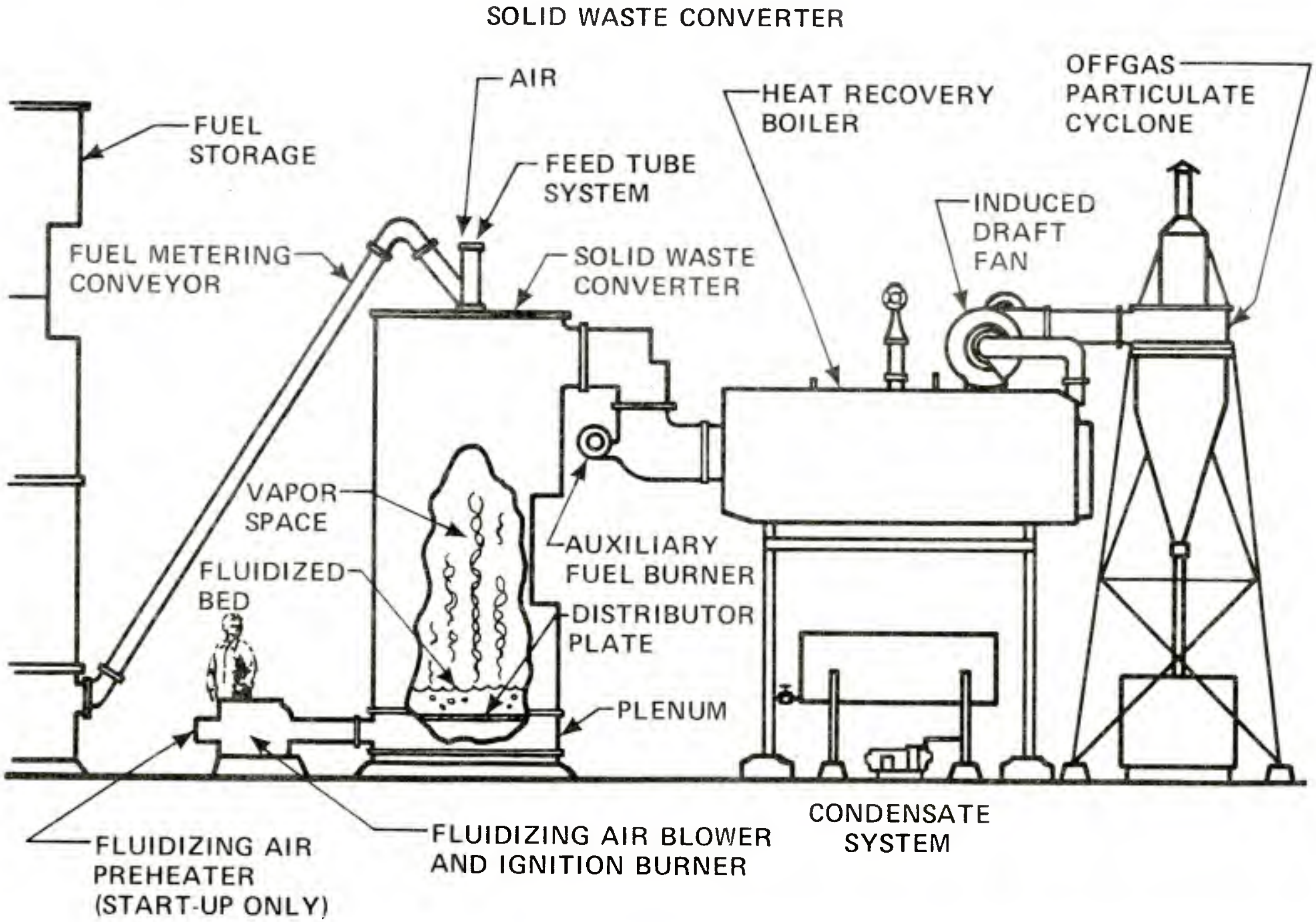

Figure 1. Direct combustion of wood waste.

Advanced Thermochemical Systems

A Department of Energy (DOE) experimental facility in Albany, Oregon, is investigating the feasibility of producing oil from wood waste and other bio-mass. Hogged wood waste is dried to reduce the moisture content from 40% to 4%, after which it is ground to a wood flour. The flour is screened and mixed with product oil (30% flour, 70% oil) to form a slurry. The slurry is pressurized to 27.6×10^6 kPa (4,000 psi), blended with a catalyst solution (sodium carbonate), heated to a reaction temperature of 371°C (700°F) and pumped into the reactor. The mixture is agitated and a carbon monoxide/hydrogen blend is added. The subsequent chemical reaction converts the wood slurry to oil. The oil is removed from the reactor, cooled, depressurized, and run through a centrifuge to remove any unreacted solids. Some of the product oil is recycled to repeat the process with the remainder sent to storage.

Pyrolysis is another technology that is being considered for converting wood waste to energy. It is an exothermic process which heats organic materials to a high temperature (500-1100°C or 932-2012°F) without oxygen, resulting in the breakdown of these organic materials into their various components. At these high temperatures most organic materials are converted to three product types: gas, liquid (oil), and solid (char). In the pyrolysis of wood waste, the cellulose breaks down into various new organic compounds which have less complex molecular structures than cellulose. A specific reaction equation for the pyrolysis of wood waste cannot be written; factors such as temperature, residence time, pressure, and the presence of catalysts, control the ratios of pyrolytic products. A generalized equation for the pyrolysis of cellulose is:

$$C_6H_{10}O_5 \longrightarrow W + X + Y + Z$$

W = Fuel gas (including CO_2 and H_2O vapors)
X = Liquid fuel (oil)
Y = Other condensables (oxygenated organics in water)*
Z = Carbonaceous solid fuel (char)

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*Note: Requires further treatment before discharge from plant.

From an energy yield standpoint, gas pyrolysis offers an advantage over oil pyrolysis. However, the gas pyrolysis plant is best adapted to a location near a large energy user to minimize pipeline and storage costs. It has the further disadvantage that the gas breaks down rapidly. On the other hand, pyrolytic oil offers the advantage of more economic storage and distribution by truck, rail, or barge. This allows greater freedom for locating the plants in close proximity to wood waste feedstocks.

There are several factors which must be considered in judging various pyrolysis processes. The first is the degree of waste preparation. Some processes handle raw feed products while others require various degrees of shredding. The degree of shredding is important because it could require expensive equipment (often with 7.46×10^5 W (1000 HP) motors), large amounts of power, and high operation and maintenance costs. Another factor is the type of solid residue left by the process. If the pyrolysis is done at temperatures in the range of 659-871°C (1200-1600°F) the yield usually includes carbon char, while a glassy, fine-grained aggregate will result at 1371-1649°C (2500-3000°F). The char is high in carbon content and represents a big (25-30%) efficiency loss (heat output vs heat content of feedstock) if it is not used for its energy content. This is one of the reasons that the Occidental Research Corporation (OXY) process recycles the char produced to the pyrolysis chamber.

Some companies claim that the char product can be briquetted or converted into activated carbon (at some expense). At this time it does not appear economically feasible to convert it to activated carbon. If char is a product of the process, its marketability is a major factor in the economics of the system as a whole. The final factor influencing economics is whether the major fuel product is a gas or a liquid.

If the gas produced has a low heating value it is impractical to transport it away from the site. It is, therefore, burned at the site and the heat is recovered in a waste heat boiler. When this is done, it nullifies one of the major advantages of the process, namely, the production of a storable or easily transportable fuel.

The Occidental Research Corporation has developed a pyrolysis process (fig. 2) which yields a liquid fuel (pyro-oil) (ref. 4). The process is being developed primarily for municipal solid waste, but it has been applied to wood waste. The process shreds the wood waste to a size of less than 8 cm (3 in.). The shredded wood is conveyed to an

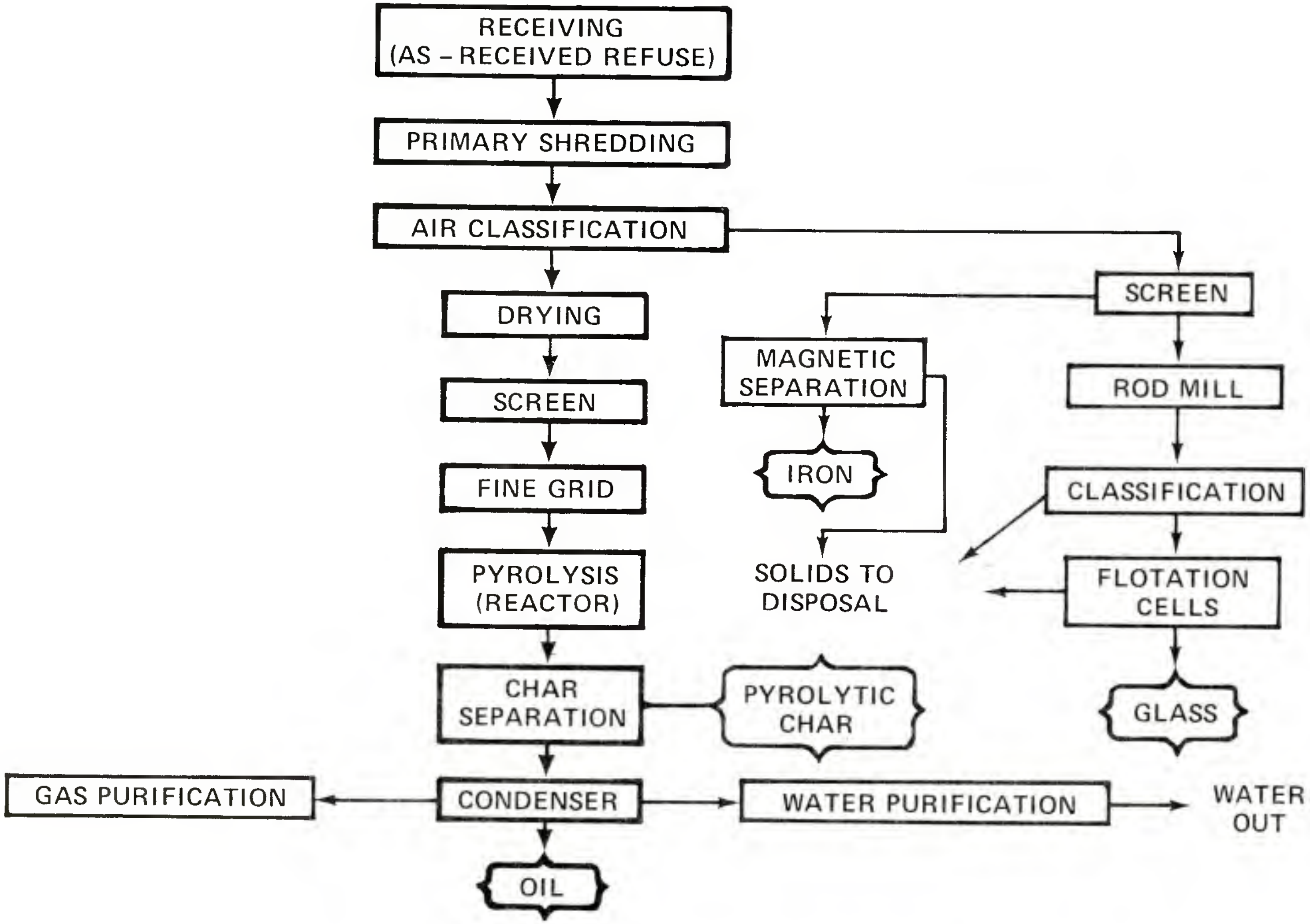

Figure 2. Flow chart of OXY pyrolysis process.

interim storage bin providing an 8-hour surge capacity. The shredded wood from the storage bin is conveyed to the air classifier which separates the wood chips of less than 8 cm (3 in.) into the overhead stream, passing through the air classifier cyclone to the secondary shredder-dryer system. Larger chips are screened to remove inorganics and recycled to the primary shredder. The secondary shredder operates under a hot nitrogen blanket and reduces the wood waste to -24 mesh, simultaneously drying the wood to five percent moisture. The finely shredded, dried wood is fed to a secondary surge system which has an 8-hour capacity, so that feedstock interruptions or maintenance requirements in the shredding system will not effect the pyrolysis process.

A screw feeder conveys a measured amount of dried wood waste to the refractory-lined reactor approximately 0.2 m (8 in.) in diameter. The wood waste is lifted by transport gas and combined with 760°C (1400°F) circulating char. Flash pyrolysis occurs in the reactor at 510°C (950°F) and converts the wood into oil, char, wax, and pyrolytic gases. Char is separated from the reaction mix in a series of cyclones and stored at 510°C (950°F) in the char surge hopper. The char then flows to the char heater where a portion is burned to raise the temperature of the circulating char to 760°C (1400°F). The heated char is then mixed with the wood waste feedstock and introduced into the reactor. Two and one-quarter kilograms (5 lb) of char are mixed with each 0.45 kg (one pound) of feedstock material.

A quench oil is used to cool the volatile portion of the pyrolysis products to 80°C (175°F). After cooling, the pyrolytic oil is decanted from the quench oil (which is recycled) and sent to storage. The reaction mix must be removed from the reaction zone quickly to prevent cracking into carbon, lighter fractions, and gas. The quenching steps that follow must, therefore, be closely coupled to the reactor.

The pyrolytic oil produced is a chemically complex organic fluid (table 2). The sulfur content is lower than that of even the best residual oils. The average heating value per 0.45 kg (1 lb) is about 24.4×10^6 J (10,500 BTU) compared with 42.3×10^6 J (18,200 BTU/lb) for no. 6 fuel oil (table 3). The heating value is lower because the pyro-oil is lower in both carbon and hydrogen and contains much more oxygen (table 2). An equal volume of pyro-oil contains about 76% of the heat energy available from no. 6 fuel oil.

Table 2. Typical properties of no. 6 fuel oil and pyrolytic oil

Property	No. 6 oil	Pyrolytic oil
Components: (%)		
Carbon	85.7	57.5
Hydrogen	10.5	7.6
Sulfur	0.7-3.5	0.1-0.3
Chlorine	--	0.3
Ash	<0.5	0.2-0.4
Nitrogen	2.0	0.9
Oxygen	2.0	33.4
MJ/kg (BTU/lb)	42 (18,200)	24.4 (10,500)
Specific gravity	0.98	1.30
kg/m^3 (lb/gal)	979 (8.18)	1300 (10.85)
GJ/m^3 (BTU/gal)	41.1 (148,840)	31.7 (113,910)
Pour point °C (°F)	18.3-29.4 (65-85)	32.2 (90)
Flash point °C (°F)	66 (150)	56 (133)
Viscosity SSU at 88°C (190°F)	340	3150
Pumping temperature °C (°F)	46 (115)	71 (160)
Atomization temperature °C (°F)	104 (220)	116 (240)

Table 3. Data from the flash pyrolysis of solid waste feedstocks

Oil	Animal waste	Rice hulls	Fir bark	Grass straw	Municipal solid waste
Components: (%)					
Carbon	64.8	62.4	60.5	58.6	57.0
Hydrogen	6.9	5.8	6.0	5.6	7.7
Nitrogen	7.0	1.4	0.5	1.3	1.1
Sulfur	0.2	0.1	0.1	0.1	0.2
Oxygen	19.8	29.4	30.7	33.9	33.6
Chlorine	0.2	0.3	0.2	0.1	0.2
Ash	1.1	0.6	2.1	0.5	0.2
MJ/kg (BTU/lb)	27.4 (11,800)	24.4 (10,400)	23.9 (10,300)	21.9 (9400)	24.4 (10,500)
Oil yield (%)	20.0	44.2	28.7	35.7	40.0
Water yield (%)	10.1	11.2	15.2	19.9	10.0

Pyrolytic oil is more viscous than a typical residual. However, its fluidity increases more rapidly at higher temperatures than that of no. 6 fuel oil. Hence, although it must be stored and pumped at higher temperatures than those required for fuel oil, it atomizes well at 116°C (240°F). During operation of the OXY plant in El Cajon, CA, it was found that increasing the moisture content from 14 to 20% made the viscosity of the pyro-oil more compatible with that of no. 6 fuel oil. Pyro-oil is slightly corrosive because it contains various organic acids as well as other organic compounds, and may require special consideration in shipping, storaging, and pumping. However, pyrolytic oil can be blended with no. 6 fuel oil and successfully burned in a utility boiler with properly designed fuel handling and atomizing systems.

Another pyrolysis process, that of the Tech-Air Corporation, Atlanta, GA (fig. 3), was initially developed at the Engineering Experiment Station at George Tech. The Tech-Air process converts wood waste into charcoal, oil, and combustible gas.

In this process, the wood waste is reduced in size by hogging (if required), then sent through the dryer which reduces the moisture to less than 10%. The dried feed is conveyed to a surge bin, then to the pyrolytic chamber where it is thermally decomposed into char and oil/gas vapors. The char is removed through the bottom of the chamber, conveyed through a water spray, and discharged. The oil/gas vapors flow upward through the bed of wood waste and exit through an opening in the top of the chamber. The vapors pass through a gas cleaner (which removes entrained particles), a condenser, a demister to coalesce the oil mist to liquid, and through the induced draft fan to a gas burner.

Approximately 50% of the gas produced is used in drying the feedstock. The pyro-oil generated from this process is similar to that produced by the OXY process. For a feed rate of 7 tons per hour, (bone dry) the output of the system is: char 1586 kg/hr (3,500 lb/hr), oil (maximum) 1427 kg/hr (3,150 lb/hr), gas (above drying requirement) 2193 kg/hr (4,842 lb/hr).

An important factor in favor of oil pyrolysis processes is that the product is salable and need not be used internally as in gas pyrolysis systems. Consequently, the onus of air pollution control is placed on the facility that burns the fuel oil, which is usually equipped with the required pollution abatement measures.

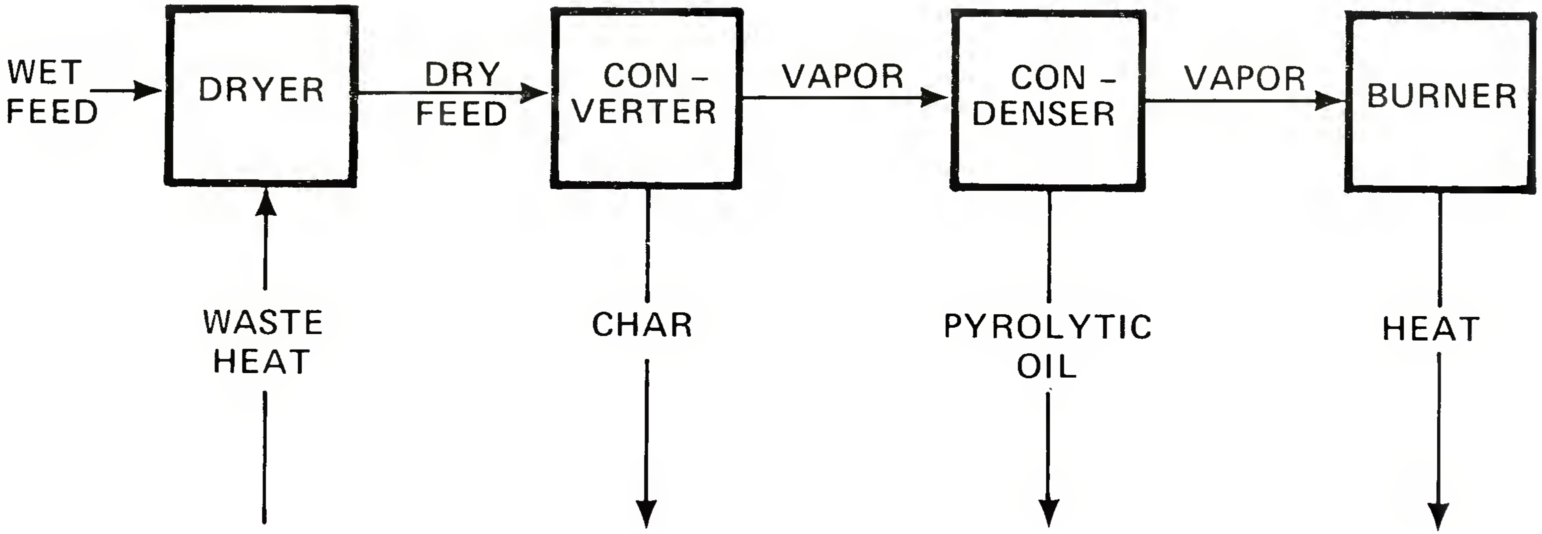

Figure 3. Flow chart of Tech-Air pyrolysis process.

In the production of liquid fuel, the pyrolytic oil in the volatile gas stream must be condensed. In addition to the pyrolytic oil, the condensate contains quench oil (if used), and the water produced during pyrolysis. These separate into oil and water phases which are physically separated. However, the water phase is contaminated with water-soluble organic compounds such as acids, aldehydes, and alcohols. This contaminated water, which may contain BOD values near 100,000 mg/L, poses serious recovery and disposal problems. Other possible emissions from the pyrolysis plant are the particulates from the shredding, air classifying, and drying systems.

Use of Wood by the Army

Like other large energy users, the US Army is looking for fuel sources to supplant fossil fuel reserves. Currently, at the site of the National Space Technology Laboratories (NSTL) in Mississippi, an Army ammunition plant (AAP) is under construction. The Mississippi AAP (MSAAP) is the first ammunition plant to be built by the Army in more than 25 years. The plant will be located on the northern portion of the NSTL site and will consist of various manufacturing complexes. It will use the latest advances in manufacturing technology and will integrate all steps of projectile manufacture at one location. Located in a dense forest in southwest Mississippi, the NSTL is surrounded by 48×10^7 m^2 (120,000 acres) of woodlands. Since the plant will consume a significant quantity of energy (table 4), NASA sponsored a preliminary investigation of wood waste as an alternate fuel source at NSTL. It was concluded from this investigation that wood waste is a viable fuel alternative at NSTL and that technology currently exists (pyrolysis, in this case) to use this energy source. The pyrolysis system studied was that of the Tech-Air Corporation, based on operating data from the Cordele, Georgia plant.

Because of its proximity to the wood waste source and its need for an alternate fuel, the NSTL/MSAAP complex is a perfect candidate for using wood waste. A detailed study is being conducted to determine the feasibility and economics of using wood waste to produce energy at the site. If feasible, similar studies can be conducted for other Army ammunition plants perhaps incorporating the concept of energy farming for those areas where natural wood resources are not abundant.

Table 4. Monthly requirements NSTL - Mississippi AAP complex

	1978	1985
Gas	14×10^8 meters^3 (50,000 MCF)	7×10^8 meters^3 (25,000 MCF)
Electricity	12.6×10^9 Joules (3.5 MM kWh)	3.5 MM kWh
Oil (no. 2)	147.6 meters^3 (39,000 gal)	39,000 gal
Coal	3.3×10^5 kg (367 tons)	367 tons
Total	7.776×10^{10} BTU	5.1985×10^{10} BTU

CONCLUSIONS AND RECOMMENDATIONS

Producing fuel from wood wastes appears to be a viable approach to future energy needs without creating new or unusual pollution problems.

Consideration should be given to using wood as an alternate source of energy at all Army ammunition plants.

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