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Design, construction and operation of a new type of gasifier for the production of fuel gas from wood waste (sawdust, chips, bark, etc.) are discussed. Data obtained from pilot plants are presented. The gasifier is inexpensive, easy to operate and has about 95% efficiency.

1. INTRODUCTION

For many years the United States enjoyed an abundant supply of energy in all forms: gasoline, heating oil, natural gas and electricity. All these fuels were taken for granted. They flowed cheaply from supplies that seemed limitless to the American public. Petroleum imports have tripled since 1964, providing over one-third of our total demand for such products. From early 1974, energy has become increasingly costly. However, despite the urgent need for conservation, our oil imports have risen above pre-embargo levels.

Major goals of the United States are to boost domestic energy production and end dependence on foreign oil. Dwindling supplies of domestic oil and natural gas will require readily and abundantly available substitutes. Energy consumers must use a "cafeteria" approach, using whatever source of energy is indigenously available, rather than depending solely upon the conventional source of fuel. The United States have an abundant supply of wood chips, sawdust, and bark, which can be used as sources of energy for raising steam and generating power for their industries.

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2. WOOD AS A SOURCE OF FUEL

It is estimated that for every tree that is harvested, as much as one third of its volume is left in the woods. During primary manufacture, an additional 50% or more of its volume is lost in the conversion process (1).

The wood residue generated can be classified into two categories. The first category consists of wood and bark residues generated in mills processing timber into primary products such as lumber and plywood. According to a study made by the Georgia-Pacific Corporation for the Mitre Corporation (2) the total mill residues generated in the United States in 1970 are estimated at about 86 million dry ton equivalent (DTE) including about 67 million DTE of wood and 19 million DTE of bark. Approximately 78% of total residues were generated in the lumber industry, 15% in the plywood industry, and the remaining 7% in the manufacture of miscellaneous wood. Table I presents the wood and bark residues used and left unused in 1970. It is estimated that 28% of all wood and bark residues remained unused. Prices of these residues fluctuate very widely. Prices of pulp chips range from $18 to $40 per bone dry ton. Table II presents some representative residue prices.

Forest residues, the second category, represent a potentially very large source of biomass for energy production. The forest residues include logging residues, intermediate cuttings, understory removal and annual mortality. The annual mortality refers to trees killed by natural agents. Data on the forest residues generated are limited. Figures presented in Table III are estimates based on the best available data. The total forest residues are estimated to be about 187 million tons excluding the waste wood generated by mortality of growing stock. Forest residues generally have no positive value to landowners at the present time, and it may be assumed most such residues are available at no cost. However, cost of collecting, reducing, and transporting logging residues are estimated at about $23 to $61 per DTE.

One of the most important properties of a fuel is its heating value. There is not much difference in the heating value of moisture and resin free wood of different species. It is about 8,300 Btu/lb. Bark, in general, has higher values than does wood. A higher proportion of resin-like compounds in bark probably accounts for the difference. A summary of average heating values for wood and bark of some species is presented in Table IV.

3. LITERATURE REVIEW

Work on the production of energy from solid wastes had started in the U.S.A. as early as 1969 as a means to combat the solid waste disposal problem. A number of combustion process have been reported in the literature. Some of these are for the production of fuel gas, whereas others are used for raising steam by the direct combustion of wood or solid waste.

Table I

WOOD AND BARK RESIDUES BY REGION IN 1970 - TOTAL, USED AND UNUSED (2)

Region*	Total Residues Generated	Residues Used		Residues Unused	
		Amount	% of Total	Amount	% of Total
	(10^6 DTE)	(10^6 DTE)		(10^6 DTE)	
Northeast	6.6	4.3	65	2.3	35
North Central	6.4	4.3	67	2.1	33
Southeast	11.4	6.9	61	4.5	39
South Central	16.7	12.1	72	4.6	28
Pacific Northwest	27.8	23.6	85	4.2	15
Pacific Southwest	8.8	5.5	63	3.3	37
Northern Rocky Mountain	6.6	4.5	68	2.1	32
Southern Rocky Mountain	1.8	0.8	44	1.0	56
Total	86.1	62.0	72	24.1	28

*Regions are defined as follows:

Northeast - Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, Delaware, Maryland, New Jersey, New York, Pennsylvania, West Virginia.

North Central - Michigan, Minnesota, North Dakota, South Dakota (East), Wisconsin, Illinois, Indiana, Iowa, Kansas, Kentucky, Missouri, Nebraska, Ohio.

Southeast - North Carolina, South Carolina, Virginia, Florida, Georgia.

South Central - Alabama, Mississippi, Tennessee, Arkansas, Louisiana, Oklahoma, Texas.

Pacific Northwest - Oregon, Washington, Coastal Alaska.

Pacific Southwest - California, Hawaii.

Northern Rocky Mountain - Idaho, Montana, South Dakota (West), Wyoming.

Southern Rocky Mountain - Arizona, Colorado, Nevada, New Mexico, Utah.

Table II

SOME REPRESENTATIVE PRICES FOR WOOD AND BARK RESIDUES, 1974 AND 1976 (2)

($/DTE)

	West Coast	South	Maine
Chips			
Softwood			
1975	25.00-37.50		
1976	40.00	25.00-28.00	40.00
Hardwood			
1976		18.00-20.00	
Shavings			
1975	3.75-5.45		
1976		7.50	
Sawdust			
1975	2.50		
1976		1.50-2.00	5.00
Bark			
1975	2.40		
1976	5.80	1.00	

Table III

ESTIMATES OF FOREST RESIDUES BY REGION - 1970 (2)

Region*	Logging Residue (10^3 DTE)	Stump-Root System Left as Logging Residue (10^3 DTE)	Total
New England	3,976	4,772	8,748
Middle Atlantic	5,331	5,060	10,391
Lake States	3,670	4,874	8,544
Central States	4,530	4,680	9,210
Southern Atlantic	11,813	12,348	24,161
East Gulf	5,622	8,718	14,340
Central Gulf	10,585	13,537	24,122
West Gulf	9,695	12,547	22,242
Pacific Northwest	18,361	24,467	42,828
Pacific Southwest	4,937	6,729	11,666
Northern Rocky Mtn.	3,600	5,125	8,725
Southern Rocky Mtn.	1,079	1,625	2,704
Total United States	83,199	104,482	187,681

*Same as in Table I

Table IV

SUMMARY OF AVERAGE HEATING VALUES FOR WOOD AND BARK OF SOME WESTERN SPECIES. (3)

Species	Higher heating value, Btu/lb (Dry) Wood	Bark
Douglas fir	8,950	9,750
Western hemlock	8,370	9,350
True firs	8,300	---
White fir	8,000	---
Ponderosa pine	9,120	---
Lodgepole pine	8,600	10,960
Engelmann spruce	---	8,820
Western larch	---	8,750
Western red cedar	9,700	8,700
Redwood	9,210	---
Red alder	8,000	8,410
Oregon ash	8,200	---
Bigleaf maple	8,410	---
Black cottonwood	8,800	9,000
Oregon white oak	8,110	---

Hammond (4) of Battelle Northwest Laboratory, Richland, Washington has reported the development of a fixed-bed gasification unit for converting muncipal waste or wood chips to a low Btu gas. The gas produced has a heating value of 100-200 Btu/cu. ft. Air and steam are used in the combustion chamber. The Purox process (5) of the Union Carbide employs a partial oxidation process using oxygen for converting solid waste to fuel gas and inert slag. The fuel gas is primarily H_2, CO, CO_2 and light hydrocarbons with a heating value of about 300-370 Btu/cu. ft. Moore - Canada of Richmond, B.C. has developed a moving bed reactor for producing a low Btu gas from wood waste using air as the oxidizing medium (6). Heating value of the gas is about 180 Btu/cu. ft.

The Fluidized Bed Combustion Chamber Process (7) consists of inert particles which upon the start up of the unit are quickly preheated by an oil or gas fired burner to a temperature of about 750°F. At this point the oil or gas burners are shut off and the wood waste is blown through the vapor space downward towards the fluidized bed. Spontaneous combustion of the wood fuel takes place in the vapor space providing the heat for steam generation. The Consumat Process (8) employs a direct combustion system to utilize solid waste for steam production. It can be operated as a batch or continuous process. Many recently installed steam plants fueled by wood or bark are the spreader-stoker type where fuel is introduced above the grate into the furnace by either a pneumatic or mechanical spreader. Part of the fuel is burned in suspension, and the remainder drops to the grates where burning is completed.

4. FOREST FUELS WOOD WASTE GASIFICATION UNIT

This system is basically developed to meet the demands of small and medium size industries located in the area where wood waste is readily available. Most average size industries cannot afford the cost of changing the entire gas, oil or coal based heating or steam generation system to a wood burning system. The Forest Fuels Wood Gasification Unit can be attached to an old boiler without any significant change in boiler rating if dry wood waste is used as fuel. This not only saves the expense of a new boiler, but may also leave the oil or gas system, previously used to fire the boiler, intact as a backup system.

5. PROCESS DESCRIPTION

The gasification process is shown schematically in Figure 1. Wood chips, bark, sawdust etc. are dried in a dryer and then fed to the top of the gasifier. The wood fuel passes down under gravity over a grate through the zone of increasing temperature. The initial burning is started by a gas torch or fuel oil. The combustion involves three basic steps: (a) distillation of volatile products, (b) conversion of residual charcoal to carbon monoxide and (c) combustion of products of distillation and carbon monoxide. The principal reactions that occur in the process are the same as those that take place in most gasification systems.

Pyrolysis step

$$\text{Wood} + \text{heat} \rightarrow aCO + bCO_2 + CH_2O + dC + \text{Hydrocarbons}$$

Oxidation and reduction steps

$$C + \tfrac{1}{2}O_2 \rightarrow CO$$

$$C + O_2 \rightarrow CO_2 + \text{heat}$$

$$C + CO_2 + \text{heat} \rightarrow 2CO$$

$$C + 2H_2 \rightarrow CH_4 + \text{heat}$$

$$C + H_2O \rightarrow CO + H_2$$

Thermodynamics and kinetics of these reactions have been studied and the data are readily available. The coefficients, a,b,c, and d will depend upon the operating conditions of the gasifier.

In the first step, wood is heated to a temperature of over 450°F, at which point destructive distillation occurs with the production of wood distillates. It is an exothermic process and proceeds until the distillation is complete, leaving a residue of charcoal. In the second step the charcoal is converted to carbon monoxide with the generation of about 3,400 Btu/lb. Some of the carbon also reacts with the moisture present to produce hydrogen. In the final step the gaseous mixture of carbon monoxide, hydrogen, oxygen, methane and nitrogen move to the exit port where they are supplied with secondary air. The gaseous mixture can be fed to the combustion chamber of a boiler, furnace or other equipment where heating is required. In this process a very limited amount of air is allowed to flow through the gasifier to maximize the production of carbon monoxide.

Since the gasification is conducted outside the boiler fire box, an oil fired system can be converted to the use of wood fuel

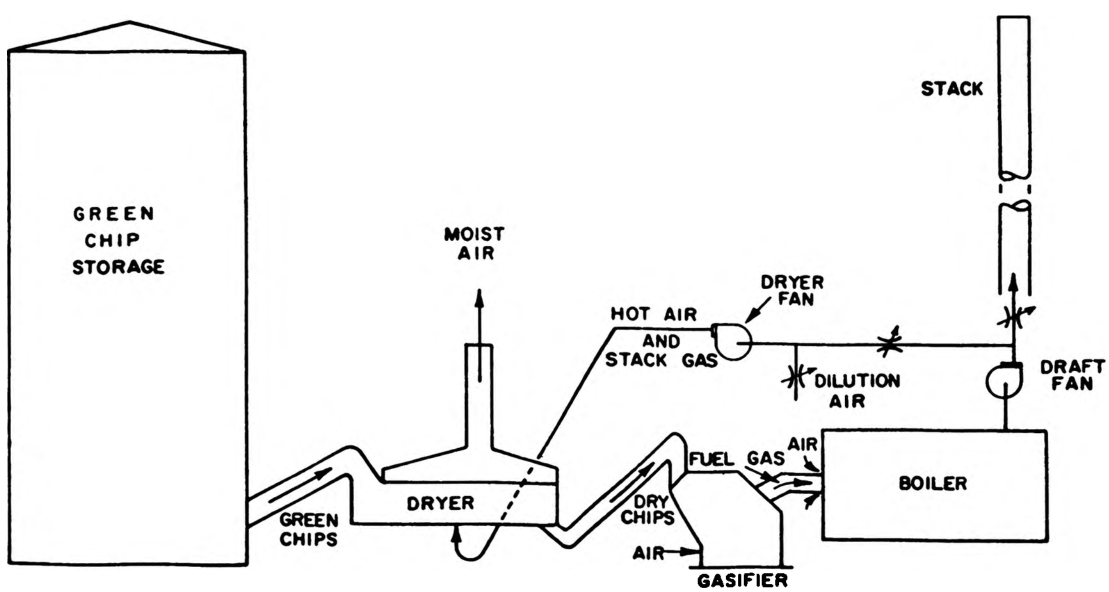

FIG. 1 FUEL GAS FROM WOOD WASTE - FOREST FUELS SYSTEM

without any significant alternation to the boiler equipment other than the removal of the oil/gas burners. The gasifier is so placed as to discharge the hot gaseous mixture directly into the fire box, thus reducing the heat losses to a minimum. Rate of combustion of wood is basically controlled by the primary air supplied to the unit.

6. EXPERIMENTAL RESULTS

Experiments have been conducted in two units. The prototype unit having a heat generation capacity of 250,000 Btu/hr. is in operation at the Department of Chemical Engineering, University of New Hampshire, Durham, New Hampshire and is used for studying such parameters as gas composition, temperature profile and pollutant emissions. A pilot plant with a heat generation capacity of 1,000,000 Btu/hr for studying design parameters is in operation at the Forest Fuels Experimental Station, Antrim, New Hampshire.

7. EXPERIMENTAL RESULTS FOR PROTOTYPE GASIFICATION UNIT

The details of the gasifier are shown in Figure 2. Wood chips about 1" to 1 1/2" dried in a tray drier to a moisture content of 14-20% (wet basis) are fed to the top of the unit at the rate of about 0.6-0.8 lb/min. The fuel gas produced from the gasifier is allowed to burn off in a fire box. Thermocouples T_1 through T_3 are installed to measure temperature in the gasification unit. Gas samples are withdrawn from ports P_1 through P_3 and later analyzed for carbon monoxide, carbon dioxide, hydrogen, methane, ethane, oxygen, and nitrogen using a gas chromatograph. Data for temperature and gas composition are presented in Tables V and VI, respectively. A uniform combustion bed is obtained with no indication of any clinker formation at the bottom of the reactor. A draft of 0.01" to 0.05" water is maintained in the gasifier using a controlled induced draft.

8. RESULTS OF THE PILOT PLANT STUDIES

Pilot plant flow diagram is shown in Figure 1. Wood chips are dried by the hot exhaust gases to about 10-20% moisture content. Chips are automatically fed by a screw conveyor to the gasification unit at a feed

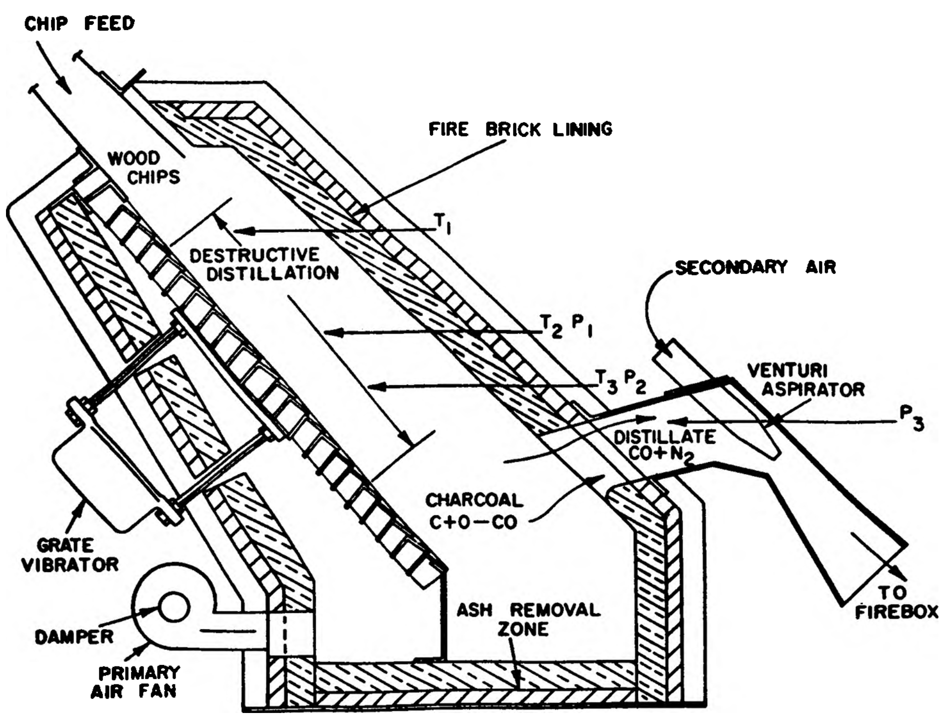

FIG. 2 FOREST FUELS WOOD GASIFIER

rate of about 125 lb/hr. The gasifier is of about the same design as the prototype except the ash is automatically removed at the bottom of the reactor. The hot gaseous mixture is fed to a horizontal marine boiler where it is burned to raise steam. The flame temperature in the boiler near the gas inlet port is about 2300°F. The rate of steam generation is about 600 lb/hr at 10 psig. Thermal efficiency of the gasification unit is estimated to be about 95%. As in the prototype unit, and induced draft with an automatic damper control arrangement is used to regulate the flow of gases. The gasifier is operated at a maximum temperature of about 1300°F. The gases generated are found to be a little richer in combustibles than those obtained from the prototype unit. The mass spectrometric gas analysis is presented in Table VII.

Clinker formation and choking were found to be the main problems particularly during the combustion of a fuel with low ash fusion temperature. These problems have been suc-

Table V

TYPICAL TEMPERATURE DISTRIBUTION IN PROTOTYPE GASIFIER

Location	Temperature °F
T_1	475 - 692
T_2	649 - 692
T_3	692 - 735
Temperature in the Fire Box	671 - 756

Table VI

TYPICAL GAS COMPOSITION IN PROTOTYPE GASIFIER

Location	Volume %						
	CO_2	O_2	CO	N_2	H_2	CH_4	C_2H_6
P_1	13.4	7.5	1.79	74.64	2.23	0.13	-
P_2	15.08	3.75	9.61	63.48	5.86	1.86	0.36
P_3	12.83	2.05	9.34	68.94	6.16	0.68	-

Table VII

TYPICAL GAS ANALYSIS FROM PILOT PLANT

	Volume %
Benzene	0.18
Hydrogen	4.19
Methane	2.28
Ethylene	0.70
Acetylene	0.45
Propylene	0.16
Carbon Monoxide	11.75
Carbon Dioxide	14.23
Nitrogen	65.31
Argon	0.75

cessfully eliminated by conducting combustion on a traveling grate with adjustable speed. Primary air supply system has also been improved with considerable reduction in grate temperatures. A six million Btu per hour gasification unit with the above modifications will soon go in operation using pine hog as fuel.

9. DISCUSSION

Wood combustion studies conducted using the prototype unit as well as pilot plant fully show the satisfactory performance of this combustion system for raising steam for industries. The fuel gas produced has a heating value of about 60-70 Btu/cu ft. and burns clean. However, the gas will have a heating value of about 80-90 Btu/cu. ft. if sensible heat is included. The Environmental Protection Agency has tested one such unit. The allowable particulate emission per million Btu is 0.1 pound per hour, while EPA tests found the gasifier emitted only 0.023 pound per hour. The gasifier uses a low air velocity. This allows ash and particulate matter to fall into the ash pit rather than being drawn up the stack by high velocity air common to most wood-burners.

The low heating value of the gas produced by this system as compared to that produced by the Batelle or Purox process is mainly due to the fact that the Forest Fuels gasifier uses air alone rather than air/oxygen and steam as used by other processes. However, this system can be modified to accept air and steam to produce medium Btu gas. Efforts in this direction are under way.

10. FIELD UNITS IN OPERATION

Based on the technical know-how acquired from the experimental gasifiers, seven field test units have been designed, fabricated and installed at various locations in the states of New Hampshire, Maine, Georgia, and Mississippi. The heat generation capacity of these units ranges from 1 to 12 MBtu/hr using sawdust, wood shavings and chips as fuel. The cost of gasifier for these units is estimated to be about $5000 per million Btu. These units have been in operation for six months to two years and are providing valuable information on the flow behavior of gases, combustion characteristics of wood waste, and overall performance of this system, enabling us to develop better and reliable gasifiers.

11. ACKNOWLEDGEMENT

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