Sonderdruck aus „Holzforschung und Holzverwertung", 31. Jg., Heft 4, Seiten 79–82 (August 1979)

RP 589
3-12-1985

Energy Recovery from Wood Residues*)

Energiegewinnung aus Holzabfällen

By H. RESCH

Introduction

Change is the essence of life, and essential changes in our lives today are caused by limited supplies of, or higher prices for, energy. Economic growth should be achieved without corresponding increases in energy consumption.

The forest products industries may be in an enviable position. Assuming a given land base and favorable climatic conditions, trees can convert, although not too efficiently, solar energy and store it in the form of wood and bark. Furthermore, foresters guarantee the renewability of this resource. Once harvested, wood can be processed using relatively small amounts of energy. For instance, producing a ton of lumber requires only about 430 kW-hrs, compared to 2700 and 17,000 kW-hrs for the same amounts of steel and aluminium respectively. In lumber and plywood production, the largest amount of energy is needed for drying operations which generally use process steam.

Trees are wonderfully efficient because they yield not only the products needed by our societies, but also the raw material to produce energy for that conversion process. We are finally close to unlocking how to utilize the entire tree. Although most logging activities still leave residues too dispersed to be economically gathered and transported to power conversion facilities, mill residues can be readily converted into energy on-site. And although wood-fire boiler systems are less efficient than oil burners, research and development efforts are making progress to improve that situation.

Last, but not least, the forest products industry must consider the impact of management beyond the "land, labor, and capital" traditionally emphasized by economists. Manufacturers must look at the design of tasks in order to substitute technology and systems for people and serendipity. Not harder work and greater exertion of energy, but better organization, incentives, technologies, and skills will improve overall productivity and reduce demands for more power. A well informed generation of forest products technologists is needed to consider the alternatives in converting wood and bark residues into energy.

Today those alternatives include processes that yield either hot combustion gases to produce steam or direct heat for kilns, veneer dryers, and other processes. Secondary fuels — such as producer gas, oil, or methanol — can be manufactured from trees and burned in place of fossil fuels. The major production activities of a firm or the needs of a specific user will dictate the feasibility of these alternatives.

Wood and Bark as Fuel

The energy of forests depends on their photosynthetic productivity. The largest portion of trees represents stored energy. The caloric values of plant components vary greatly and increase as carbon content increases:

	Mono saccharides	Polysaccharides	Protein	Lignin	Fat
Carbon (%)	40	42	53	63	75
Energy value (kcal/kg)	4000	4200	5700	6000	9500

Trunks, crowns, and surface litter contain about 4500 to 5200 kcal/kg of dry matter (8). However, the productivity of forest land reflects species composition and geographic location. In tropical climates, one hectare may produce up to 80 dry metric tons in one year. In temperate zones, the maximum production of 74 dry t/ha/yr is reached by young hardwoods (3). This production falls off quite rapidly with age, so mature conifers yielding 10 to 25 t/ha/yr outperform the hardwoods.

The heating values of wood and bark vary with species and chemical composition. The chemical composition of a fuel is determined by the ultimate analysis which mainly expresses the relationship of hydrogen to carbon to oxygen. Proximate analysis of a fuel determines the percentages of fixed carbon, volatile matter, and ash.

Ultimate analysis shows that the main components in one metric ton of dry wood and bark fuel commonly found in the American Pacific Northwest are (6):

	Molecular weight	Dry weight (kg)	kg-moles
Carbon (C)	12	516	43
Oxygen (O_2)	32	416	13
Hydrogen (H_2)	2	61	30
Nitrogen (N_2)	28	1	
Ash		6	

Proximate analysis of woods, dry basis, from the American Northwest gives these following average values (9):

	Volatile matter (%)	Charcoal (%)	Ash (%)
Wood	83.8	15.6	0.5
Bark	74.7	24.0	1.3

Typical wood and bark fuels vary in two more important ways; they contain moisture and, frequently, considerable amounts of inorganic matter inadvertently added during logging or yarding operations. Moisture content is expressed on either a wet or dry basis. The former reflects the ratio of the weight of moisture in a fuel to the total fuel weight, including the water. Dry weight is based on the weight of moisture divided by the weight of ovendry fuel.

Table 1. Ash and Moisture in Typical Wood Fuels

Fuel	Size (mm)	Moisture (%) Wet Basis	Ash (%) by Weight
Sander dust	≤ 0.8	2— 8	0.1— 0.5
Shavings	0.8— 13	10—20	0.1— 1.0
Sawdust	0.8— 10	25—40	0.5— 2.0
Hogged bark	0.8—100	25—75	1.0—20
Yard cleanup	≤ 100	40—60	5 —50
Clarifier sludge	Mush	70	< 75
Forest residues	Any	30—60	3—20
Fly carbon	Small	0	1—10

The theoretical maximum thermal value — that is, the higher heating value — of a fuel is the heat of combusting a unit (dry weight) of that fuel (2). For wood and bark of North American species, the higher heating values range from 4140 to 5980 kcal/kg on an ovendry basis (5).

The effective heating value of wood and bark fuel is calculated by subtracting unavoidable heat losses from the higher heating value. Such heat losses stem from

---

*) A Special Paper Invited for the Eighth World Forestry Congress in October, 1978, in Indonesia and held under sponsorship of the Food and Agricultural Organization of the United Nations.

The author: Prof. Dr. Helmuth Resch, Head, Department of Forest Products, School of Forestry, Oregon State University, Corvallis, Oreg. 97331, USA. This is paper 1248 of the Forest Research Laboratory, Oregon State University.

moisture that must be evaporated, the presence of hydrogen which combines with oxygen to form water, air exceeding that needed for optimum combustion, radiation, and convection cooling. If fuel is not directly converted to heat by combustion, but instead is used as feed stock for generating gas or oil, more heat is lost in that conversion.

Most wood and bark fuels are processed through hammer mills, often referred to as hogs and thus originating the term, "hogged fuel". Sometimes predrying fuel is desired, especially when hydraulic debarkers are used and the material is stored outdoors in heavy rains. Dry fuel is also needed for pelletizing, compressing the wood to one-third its original volume. Pellets have advantages when very uniform fuel is desired, when it is to be transported over certain distances, or both.

To properly size energy conversion units, mill managers must determine the amounts and kinds of products and residues produced in their operations. Experience in North America indicates that sawmills and plywood plants produce these relative amounts (2):

Table 2. Products from the Manufacture of Lumber and Plywood

Lumber Manufacturing

	Percentages by	
Item	Volume	Weight
Lumber	39.4	38.7
Coarse residue	26.0	25.7
Sawdust	13.4	13.1
Planer shavings	9.7	9.6
Bark	11.5	12.6
TOTAL LOG	100.0	100.0

Plywood Manufacturing

	Percentages by	
Item	Volume	Weight
Plywood	44.6	44.1
Log trim	4.4	4.4
Coarse residue	4.8	4.7
Veneer trim	32.6	32.2
Sander dust	2.1	2.0
Bark	11.5	12.6
TOTAL LOG	100.0	100.0

Combustion of Wood and Bark Fuels

Direct combustion, the most common method of converting these fuels into energy, produces hot gases that are used either directly for drying lumber and veneer or for generating steam.

Combustion of wood and bark fuels is a rapid exothermic process that occurs mainly as a gaseous-phase reaction when 75 to 85 percent of the fuel is volatile. The remaining carbon can burn in the solid state. Combustion efficiency appears significantly affected by the interaction of fuel moisture content, the amounts and distribution of excess air, and fuel size.

Dehydration of the fuel is the first step in the burning process. Then volatile components of the wood are heated to between 100 and 600° C so they evaporate. The change in molecular structure due to chemical decomposition is called pyrolysis.

Because combustion is both an oxidation and reduction process giving off heat, the volatile fuel component must be well mixed with oxygen. The rate of burning is effectively controlled by the amount of oxygen available for reaction. First, carbon combines with the oxygen to form carbon dioxide, then hydrogen combines with oxygen to form water.

Considering the fuel components listed earlier, the amount of oxygen required for complete combustion can be calculated: $C + O_2 => CO_2$. On the basis of dry fuel, 43 kg-moles are needed to combine with the 43 kg-moles of carbon. For the reaction, $2 (H_2) + O_2 => 2 (H_20)$, 15 kg-moles of oxygen are needed to burn 30 kg-moles of hydrogen. Thus, a total of 58 kg-moles of oxygen are required to burn the fuel. Because the fuel already contains 13 k moles, the air must supply only 45 kg-moles of oxygen. These 45 kg-moles of oxygen occupy 1009 m^3 under standard conditions. Taking the oxygen content of air as 21 percent by volume, burning one ton of dry fuel requires about 4805 m^3 or 6170 kg of standard air.

The amount of air required for combustion is termed theoretical air. In reality, however, that amount is insufficient for complete burning. Moisture must be driven off from the fuel, and all fuel particles must be properly mixed with air. Therefore, combustion requires excess air, expressed as percentage of the theoretical air, that ranges from 25 to 150 percent depending on the burning system. Too much excess air is detrimental because it reduces the thermal efficiency of a system, cooling the combustion reaction and thereby decreasing the reaction rate. Forcing too much air into a system not only requires more fan power but, more importantly, it also increases gas velocity in the furnace. This reduces residence time of the fuel, leading to incomplete combustion and emission of air pollutants.

So-called flue gases result from the combustion of hogged fuel. Dry flue gases with no excess air contain about 20.3 percent carbon dioxide, 79.7 percent nitrogen, and no oxygen if combustion is complete. This can be determined by measuring the carbon dioxide content with a flue gas analyzer.

The moisture content of the fuel must be known because heat is necessary to evaporate this moisture. It not only reduces the heat value of the fuel, but variations in moisture content also make optimum combustion conditions difficult to maintain. When the moisture content of a fuel that is being fed into a combustion unit increases, the rate of combustion will decrease. Vice-versa, when suddenly very dry fuel is added to a well-adjusted combustion of wet fuel, an oxygen deficiency will occur and unburned carbon particles will pollute the air.

The efficiency of the combustion system is generally expressed in percent by subtracting from 100 percent all available heat lost due to moisture in fuel and air, the reduction reaction, excess air, escape of dry gas and unburned carbon fuel, radiation from the combustion unit, and minor unaccountable factors. The effective heating value per unit weight of wood and bark fuel can be expressed as the product of percent efficiency, percent fuel, and higher heating value per unit weight.

In boiler systems with grates, the effects of fuel size and moisture content can be minimized by properly adjusting the percentages of air under and over the fire (7). The combustion efficiency decreases as moisture content increases, especially for small-sized fuels when most of the air is fed unter the grate. However, the influence of moisture content becomes negligible when airflow under the grate is limited and most combustion air is introduced not too high above the fire. Such air distribution, coupled with efficient combustion, also reduces the potential for air pollution.

Combustion efficiency and capacity of exhaust gases at the stack can be improved even more so by burning the fuel in a two-stage combustion (7). First the solid carbon portion of the fuel is burned on the grate with very low gas velocities, using only 10 percent of the total air as underfire air. The second stage burns the volatile portion of the fuel at the level of the overfire inlet ports.

Inorganic components of fuel do not contribute to combustion, but are important because they may hinder it. Ash plugs grates and passageways through heat exchangers, erodes boiler tubes, and requires mechanical collectors that should be designed according to results of the proximate analyses. When exhausted by gases, ash pollutes the air. Also, salt contained in fuel derived from logs stored in seawater may corrode vital parts of a burning system.

In summary, these fuel characteristics are important when designing combustion equipment and calculating optimum combustion conditions. The oxygen content of the fuel, determined by ultimate analyses, must be supplemented by oxygen from the air for complete combustion. The ultimate analysis is used to determine the relationship between flue gas composition and the amount of excess air.

Energy Conversion Systems

Boiler systems integrate units for combustion and heat exchange. They are served by an in-feed system with fuel preparation, storage and conveyance, and preheating and transport of air. If steam production is the goal, a water treatment and recycling system is connected to the heat exchanger. Monitoring and control devices, as well as trained operators, should guarantee the proper functioning and performance. In recent years, pollution control devices such as scrubbers, cyclone separators, bag house filters, and electrostatic precipitators have become mandatory additions.

Boiler capacity expresses the steam generation rate at a certain temperature and pressure, usually in boiler horse-power, amount of steam generated per unit time, or kilowatts. The generated steam may be used as processed steam or to drive turbines.

Boiler systems differ in furnace and heat exchanger designs. The most common furnaces are spreader stokers or Dutch ovens, but suspension burners are being installed more and more. In most designs, the hot combustion gases from the furnaces transfer that energy through heat exchangers with either water tubes or fire tubes. In the former, more common arrangement, the hot gases flow around water-filled tubes. In the latter, turbulent gas flowing through tubes efficiently transfers heat to water circulating around them.

The walls of spreader stoker furnaces commonly are lined with water-filled heat exchange tubes. The fuel is fed into the furnace from above, so a high proportion is burned in suspension and the larger pieces fall onto a grate below. The fuel feeding system must be properly operated with the hogged wood and bark spread uniformly, either pneumatically or mechanically. The spreader stoker has low construction and maintenance costs because usually very little refractory is installed and, therefore, little has to be replaced when extended maintenance is necessary. Without a large mass of refractory to maintain uniform temperatures, the combustion air should be preheated.

The single-chambered Dutch oven and its variant, the fuel cell, are older furnace designs using a large amount of refractory to store heat and radiate it back to a conical fuel pile situated on grates. With this system, variations in fuel composition can easily upset the proper balance between underfire and overfire air. The fuel cell is more flexible and responsive to variations in steam demand than the single-chambered Dutch oven. The grate is also located at the bottom of a refractory-lined primary combustion chamber where partial burning occurs. Combustion of the volatile components of the fuel is completed in a secondary chamber above. Both basic systems have high capital and maintenance costs mainly because of the fire brick which has to be replaced from time to time.

Newer, less expensive multi-chamber combusters have been introduced during the last decade. They gasify the fuel in the first chamber by burning with an inadequate air supply, then complete combustion in additional burning space.

These furnaces have diverse grate designs. Grates may be air- or water-cooled; stationary, reciprocating, or continuously moving; horizontal or sloping; and perforated with pin holes or slots. Although grates are usually manufactured of special steel, refractory has also been used. A specific kind of grate system should be selected according to furnace design and fuel characteristics.

Suspension burning systems have had great appeal in recent years, in part because of their low capital costs. Finely divided fuel is suspended in air and combusted in vortex or cyclone burners so grates are unnecessary. Particle size and moisture content of the fuel, as well as residence time in the burner, are critical because fines may be carried out of the stack with fly ash and large pieces may fall through the airstream to the bottom without having burned completely. Dry fuel, mainly sander dust, is preferred because the combustion efficiency decreases as moisture content increases. Some units melt the ash in the combustion chamber, reducing the potential for air pollution; however, the ash must be removed by slagging. Also important are the fuel metering unit and the entire fuel preparation system which may include predrying.

Fluidized bed combusters are an innovation in the forest products industry. The fluidized bed consists of noncombustible particles, usually sand, in a chamber with an orifice plate on the bottom. Gas is forced through these orifices upward into the sand and, as the rate increases, the particles begin to float. The gas-solid mixture behaves much like a fluid, exhibits a hydrostatic head, and permits light particles to float on the surface while heavier ones sink to the bottom. Supplementary fuel is needed until the temperature reaches about 400° C, and the system is usually operated around 700 to 800° C. The preheated sand particles intimately contact the added wood fuel, resulting in a high rate of heat transfer. They also act as a heat sink, stabilizing combustion. Fluidized bed combusters allow for wide variation in the size and moisture content of fuel particles — for example the moisture content may be as high as 62 percent (wet weight basis).

Wood gasification through pyrolysis uses either shaft reactors or fluidized beds. In the former, hot gases pass counter to the flow of small, fairly uniform fuel particles that are coarse and dry. Usually charcoal is formed at temperatures above 400° C, and gases and liquids are driven off although they alone may be produced if the char is fully consumed. Gasifiers in connection with gas scrubbing equipment will produce a clean, gaseous fuel for use in conventional gas burners. They represent technology somewhat more complex than simple combusters. A number of processes are not yet technologically proven or economically feasible. In most cases, they are not promising for smaller forest products' firms, but might be integrated into larger operations or used at centralized conversion plants.

Pyrolysis to produce oil falls into this category (1). The pyrolitic reaction takes place in the presence of either carbon monoxide and water or synthesis gas and water at temperatures from 250° C to 425° C and at pressures from 100 to 250 kp/cm^2. Yields of heavy oil or bitumen may be close to 60 percent by weight.

Methanol production has been suggested as a logical extension of the wood gasification process. After carbon dioxide, nitrogen, and hydrocarbons are removed, hydrogen and carbon monoxide are converted to methanol at elevated pressures of 175 kp/cm^2 (4). Methanol can be used directly as a fuel or, of course, as feedstock for the manufacture of other chemicals, specifically formaldehyde, an important ingredient in adhesives.

Summary

Economic growth is to be achieved without correspondingly increasing energy consumption. From wood and bark residues, forest products industries have the potential to internally generate the greatest proportion of the energy they need. Technologists must understand the heat content of wood fuels and the alternatives available to recover it.

Forests, depending on composition and site, produce up to 80 dry metric tons of wood and bark per hectare per year with heat contents between 4,500 and 5,200 kcal/kg. Residues from sawmilling and plywood manufacture amount to about 60 percent of the tonnage being converted into forest products. Carbon and oxygen are the main components of the fuel that provides about 80-percent volatile matter and 20-percent charcoal.

Combustion is a rapid exothermic process consisting of oxidation and reduction reactions preceded by dehydration. Theoretical air for these reactions and excess air, ranging from 25 to 150 percent, is required for drying and proper mixing with all fuel particles.

The efficiency of a combustion system depends on the heat content of fuel as well as heat losses due to moisture, the reduction reaction, excess air, escape of dry gas and unburned carbon fuel, radiation from the combustion unit, and minor factors. Contents of inorganic matter also must be considered in specifying combustion equipment.

Boilers incorporating a furnace and heat exchanger of various designs are the systems most commonly used to convert energy. Different designs with various characteristics include spreader stokers, Dutch ovens, fuel cells, multi-chamber combusters, and suspension-burning systems like the fluidized bed combuster. Wood can be pyrolyzed to produce gas, but the production of oil or methanol is still in the precommercial phase.

Zusammenfassung

Industrielles Wachstum muß zukünftig ohne übermäßige Erhöhung des Energiebedarfes erzielt werden. Die holzverarbeitenden Industrien haben oft den Vorteil, daß sie den größten Teil ihres Bedarfes an Wärmeenergie aus Holz- und Rindenabfällen decken können. Kenntnis des Energiegehaltes dieser Stoffe und der verschiedensten Umsetzungsmöglichkeiten ist aber notwendig.

Der Wald kann, je nach Zusammensetzung und Standort, eine Holz- und Rindenmasse bis zu 80 Tonnen atro per Hektar und Jahr mit einem Wärmegehalt von 4500 bis 5200 kcal/kg erzeugen.

Holz- und Rindenabfälle der Säge- und Sperrholzwerke betragen bis zu 60 % des verwendeten Rohmaterials. Chemisch gesehen bestehen diese hauptsächlich aus Kohlenstoff und Sauerstoff, welche zu zirka 80 % in brennbare Gase und zu 20 % in Holzkohle umgesetzt werden können. Die Verbrennung, d. i. die schnelle exotherme Umwandlung nach vorhergegangener Dehydration, besteht aus Oxydations- und Reduktionsreaktionen. Um schnelle Trocknung und gute Vermischung der Luft mit allen brennbaren Teilchen zu erreichen, ist es je nach Feuerungssystem notwendig, der theoretisch errechenbaren Verbrennungsluft noch 25 % bis 150 % Zusatzluft zuzuführen.

Die Feuerungsleistung von Verbrennungsanlagen hängt nicht nur vom Wärmegehalt des Verbrennungsmaterials, sondern auch von den Wärmeverlusten ab, die sich bei der Dehydration, den Reduktionsvorgängen, der Erwärmung der Zusatzluft, dem Entweichen von brennbaren Gasen und durch Wärmeleitung und -strahlung ergeben.

Gebräuchliche Dampfkesselanlagen werden mit verschiedensten Wärmeaustauschern gebaut und weisen, je nach Bauart, gewisse Vor- und Nachteile auf. Pyrolyse zur Erzeugung von Heizgas kann heute schon praktisch angewandt werden, während die Erzeugung von Öl oder Methanol noch nicht ökonomisch vertretbar erscheint.

References

(1) Appell, H. R., et al.: Conversion of cellulosic wastes to oil. Investigations Report 8013. U. S. Department of the Interior, Bureau of Mines, Washington, D. C. 1975.

(2) Corder, S. E.: Wood and bark as fuel. Research Bulletin 14. Oregon State University, Forest Research Laboratory, Corvallis, Oreg. 1973.

(3) Evans, R. S.: Energy plantations: should we grow trees for power plant fuel? Information Report VP-X-129. Department of Environment and Canadian Forest Service, Western Forest Products. Laboratory, Vancouver, B. C. 1974.

(4) Hokanson, A. E., and R. M. Rowell: Methanol from wood wastes: a technical and economic study. General Technical Report FPL-12. U. S. Department of Agriculture, Forest Products Laboratory, Madison, Wis. 1977.

(5) Ince, P. J.: Estimating effective heating value of wood or bark fuels at various moisture contents. General Technical Report FPL-13. U. S. Department of Agriculture, Forest Products Laboratory, Madison, Wis. 1977.

(6) Junge, D. C.: Boilers fired with wood and bark residues. Research Bulletin 17. Oregon State University, Forest Research Laboratory, Corvallis, Oreg. 1975.

(7) Junge, D. C.: Investigation of the rate of combustion of wood residue fuel. Technical Progress Report to U. S. ERDA. Oregon State University, School of Forestry, Corvallis, Oreg. 1977.

(8) Ledig, F. T., and D. I. H. Linzer: Fuel crop breeding. Chem. Tech., January, 1978, p. 18—27.

(9) Mingle, J. G., and R. W. Boubel: Proximate fuel analyses of some western wood and bark. Wood Sci. 1 (1): 29 (1968).