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ABSTRACT

This paper presents an overview of current sources and forms of raw materials for wood energy use and the types of machines available to convert them to the desired form for boiler fuel. Both the fuel source or raw material, and the combustion furnace will dictate the requirements for the processing system. Because of the wide range of processing equipment available, systems can be designed to meet most wood burning boiler requirements.

INTRODUCTION

Wood has served as a major source of energy for man since before recorded history. During the early development of the United States, wood was the fuel that sustained homes and industry. Consumption of wood fuel peaked in the 1870's at about 3 QUADS (10^{16} BTU's) per year and then declined fairly steadily through the 1960's (10). This decline has reversed since the 1974 Arab oil embargo, so that wood and wood wastes now provide an estimated 2.6 QUADS of energy per year. Projections show the trend of increasing use of wood as an energy source will continue (4).

To meet this growing demand, it appears that more and more of the wood will have to come from forest biomass and other industrial sources. Mill residues will continue to play an important role as an energy source, but there are other demands for this resource. Industrial production and efficiency can affect availability of residues. This means that the growing need for energy will need to be met by the processing of green wood at remote sites and then transported to the use point, with some final processing to meet particular needs at the conversion site.

CHARACTERISTICS OF RAW MATERIALS

Raw materials that can be converted to energy wood range greatly in size, form, and source. All factors must be considered when deciding on the systems and costs involved in processing these various materials. Depending on the cost of processing, transportation, and alternate fuels, some energy wood resources may not be economically competitive. The four main categories of energy wood that will be

considered in this paper are forest residues, smallwood and pruning, waste wood, and mill residue.

Forest Residue

This source of energy wood can be in the form of unmerchantable cull logs, limbs, tops, and small, low-quality residual trees left after harvesting. The form of these materials can vary widely from one region of the country to another because of forest type and the influence of markets for forest products. Generally these residues are of a larger size in the West, because old growth timber stands are still being harvested. In the East, residues are composed more of low-quality hardwoods and small trees. In both cases the amount of available forest residues exceeds demand, and raw material costs are minimal. However, cost of harvesting or gathering, processing, and transportation to a boiler site can exceed the dollar value per BTU when compared to the cost of conventional fuels such as coal and oil.

Smallwood and Prunings

These potential energy sources can be in the form of small trees ranging in diameter from 1 to 5 inches that may be grown specifically as an energy source, thinnings from forest plantations, or small understory trees growing under a more mature forest. The small size of these materials makes processing easier, but the low volume of wood per piece requires highly efficient handling systems to avoid excessive costs. Disposal of prunings from large commercial orchards has long been a problem. Because most orchards are located near large metropolitan areas, prunings can have a high potential as an energy resource, since processing and transportation costs can be offset by the expense of other disposal methods such as burying in a landfill.

Wastewood

Wastewood and scrapwood come in many forms and can be generated from a number of sources. Material in this category can come from secondary manufacturing processes, end users, and demolition of structures. Forms include broken pallets, mill trimmings, railroad dunnage, and structural members and siding from buildings. These materials are less uniform, in rougher form, and may contain a high level of foreign material that must be extracted during the preparation process for energy use. Sources of these materials are not as dependable as others for energy wood, but the advantage is that there is no other use or demand for this wood, and use as a source of energy is an alternative to disposal in a landfill or open burning.

Mill Residue

Residue generated during the production of wood products is generally the most readily available and easiest to prepare for energy use. In

many cases this residue is available at little or no cost. These materials may be in the form of bark, sawdust, shavings, bolt ends, knot rings, or veneer clippings. Wood in these forms is generally of low-moisture content and will only need to be run through a hog or hammermill to meet most conversion needs. Some problems include low availability during periods of reduced manufacturing production and increasing demand for uses other than that of energy production.

BURNING METHODS

Just as raw material characteristics influence the choice of processing systems, so does the method in which the fuel will eventually be converted to energy. Two fuel properties that can greatly affect the efficiency and operating ability of the chosen combustion method are moisture content and particle size. Upon entering a furnace, wet fuels must first evaporate their water content before energy can be released. Thus wet fuels burn more slowly and are less efficient because of the heat lost to evaporation. Particle size is important for several reasons. A small particle size allows for faster combustion, will have more surface area to allow speedier moisture evaporation and greater oxygen exposure, and can be easily suspended in a suspension type burner (12).

Pile burning is the simplest method of direct combustion. Two common pile burning techniques are the dutch oven and the stoker feeder. The dutch oven utilizes gravity to help place the wood on top of a refractory grate through which an under-fire airflow is maintained. An over-fire airflow is also required to induce turbulence and to provide additional oxygen for combustion. Dutch ovens can utilize wet fuels of almost any consistency; however, control is difficult and efficiency is usually low.

Stoker feeders offer several improvements over the dutch oven. First, instead of a gravity feed, stoker feeders utilize either a mechanical or pneumatic system to "carry" or "blow" the fuel into a boiler's fire box. Second, stoker feeders cover the grate with a thin bed of fuel rather than a pile as in the dutch oven (8). Stoker feeders do not require dry wood, and can accept a range of fuel particle sizes. This can increase the heat release rate as the small particles are burned in suspension while the larger particles are consumed in the thin bed on the grate (6).

Since dutch ovens generally have very slow flame propagation due to the low surface area exposed to oxygen in the pile, the fluidized bed method of burning was developed (1). The fluidized bed process utilizes a bed of heat-resistant sand, through which preheated air is forced. This gives the bed fluid properties. The fuel not only receives the benefits of increased oxygen exposure when added on top of this bed but the fuel particles are also constantly abraded by the sand, which exposes unburned wood to the oxygen (15). Wet wood and low-grade fuels can be burned efficiently using fluidized beds (6).

Suspension burners require small particle sizes and low moisture content in order to fully suspend the fuel in a turbulent air stream for quick and efficient burning. This method requires that fuel moisture be below 15% and particle size be less than one-fourth inch (6).

PROCESSING

Size reduction processing can begin at the logging/harvest site where residual trees, cull material, limbs, and tops must be reduced to a form that will allow for an easy and economically feasible form of removal, transport, and handling. This initial form may or may not require additional processing before burning. The most common form of primary reduction is whole-tree chipping, but shredding, grinding, and chunking may also be used.

Chipping

There are two basic types of in woods chipper--portable and mobile (16). Portable chippers are available and in use by some harvesting operations, but mobile chippers are still in the prototype and development stage. Portable chippers are confined to the landing or deck area, where all the material to be processed is brought -- usually by skidding and in the form of whole trees. In general, the chipper will self-load the material onto a mechanical infeed that directs it into the rotating chipper-disk or chipper-drum. The resulting chips are then either blown into a van for transport or discharged onto the landing for storage (16). Portable chippers are generally high-production, high-cost machines and thus require highly efficient felling and skidding systems in order to utilize, their capacity.

Mobile chippers travel to the stump in order to process whole trees and residues. Mobile chippers are available in three types--chipper forwarders, chip harvesters and chip harvester forwarders. Chipper forwarders travel to the felled tree, self-load all usable material, chip it, and transport the resulting product for eventual unloading at the landing. Mobile chip harvesters are not only capable of loading and chipping, but they also fell the material to be processed utilizing a "swath-felling" technique. The resulting chips are not forwarded by the same machine but are discharged into another vehicle for forwarding. Chip harvester forwarders accomplish all the tasks of the mobile chip harvester while also forwarding all chipped material to a convenient unloading point (16).

Grinding

The rotary hopper or tub grinder is another method of primary size reduction. This form of processing is available for a wide range of uses due to its lower cost and its ability to process a much wider variety of raw materials than chippers. It appears that grinding may

prove more economically feasible than portable chippers for the reduction of tops, limbs, and other logging slash. This reduction can be carried on simultaneously with the harvest of sawlogs or pulpwood. Tub grinders are also being used as processors for orchard prunings. Despite its many uses, the lower production rate of present grinders, compared to chippers, could prove to be a drawback in some cases.

The rotary tub grinder begins processing when raw material is fed into the top of its cylindrical or sloping-sided hopper. The slow rotation of the hopper causes the material to move down into a large hammermill located in the stationary floor. After being "sheared-off" by the hammermill, cutters, the material passes into a chamber where it is ground against sizing screens, through which the final product is passed. This reduced material can be discharged pneumatically or by a belt elevator (3).

Chunking

Still in the developmental stage, chunking has recently been introduced as a means of wood-fuel size reduction. It is felt that wood chunks overcome some of the disadvantages of chips as a fuel source. Chunks are also thought to be a better form for drying during storage (5). The disadvantages of chips are: (a) small particle size--some burning methods have high under-fire airflow velocities that can cause small chips, etc., to be carried up the stack before combustion has been completed; (b) low bulk densities--the smaller the chip size the greater the proportion of inner particle void-space, - thus chips take up more volume than chunks; (c) chip intermeshing--because of their flat plate shape, bridges can form that impede material flow, and the chips can form dense mats that restrict the under-fire airflow in certain burners.

The chunking machine being developed by Arola et al. (5) utilizes a rotating disc mounted on a horizontal shaft. The disc contains three tapered, curved blades, which, when tested, sheared-off horizontally fed stems between 5 and 8½ inches in diameter at an average rate of 36 cubic feet per minute. The study also indicated that the energy requirements for chunking were about one-third of what would be required for whole-tree chipping (5).

Hogs

Hogs are generally composed of high-speed rotating drums with rows of knives or hammers that can reduce even large material into chip-size pieces. Screens are used to control particle size so that the unacceptable large pieces are sent back through the mill. Because of knife wear and breakage, hogs are extremely sensitive to dirty or contaminated material, making cleaning necessary when used with certain material sources (9).

Hammermills

Hammermills are generally employed after hogging when a very finely ground fuel is needed, as with suspension burners. A hammermill beats and grinds the fuel against a sizing screen until the material is able to pass through. Hammermills are very moisture sensitive and usually require that the moisture content be below 14 percent (13). For this reason, hammermills are generally not used until some sort of drying process has taken place (5).

Shredding

Adaptable for use both at the logging site or at the burning site shredding has several advantages over other size reduction methods. These advantages are: (a) lower energy requirements than hogs or hammermills-shredders tear, break, and crush instead of just hammer, and thus are able to accomplish a similar size reduction with less applied energy at lower tool speeds; (b) uniform finished product size; and (c) less possibility of jamming and breakdown due to the inclusion of foreign objects (pieces of metal, rocks, etc.) in the material being processed because of its high torque and low speed. This eliminates the need for a cleaning phase of the wood prior to size reduction (2).

The shredder has a large downward-sloping inlet that can be equipped with feeder arms for low-density material. This inlet directs the material onto two horizontal, counter-rotating shafts equipped with intermeshing shredding discs. The material is pulled between the rotating discs where it is simultaneously sheared, crushed, and broken. The resulting material is then discharged onto a conveyor belt for transportation to either a storage area, further processing, or burning. Skogsarbeten measured the capability of the shredder as from 70 to 100 m per scheduled hour for "fresh" lumber wastes with dimensions up to 150 mm and 100 to 150 m per scheduled hour for bark (2).

At the burning site; secondary reduction methods may be necessary to further reduce the raw material size. This further reduction depends on the size requirement of the burner or other conversion process. Hogging is generally the reduction method used, with hammermills being employed if an even finer reduction is required.

Cleaning

To reduce damage and maintenance, material processed by chippers, hogs, and hammermills must be relatively free of dirt, rock, and metal particles. Modern burners also require clean fuel, since dirty fuel can create problems by causing abrasion, plugging, slagging, and increased pollution.

One way to reduce fuel contamination after processing is to only use storage areas that are paved. Unpaved storage has been found to contribute significantly to dirt contamination. Other methods presently used

to reduce or eliminate contamination are: disc screens, air screens, the flotation method, and magnets (9).

Disc screens are a series of rotating discs placed close enough together so that when the fuel material bounces across their surface, the smaller dirt and rock particles are able to fall through. Air screens utilize wire mesh to support the fuel material. Air is forced through the screen from below, lifting the light-weight fuel particles and allowing the heavier contaminants to fall through the screen. The flotation method also takes advantage of the differences in density between the fuel and its contaminants, using flume water as a separation medium. Since the fuel particles float, they are transported by the water while the contaminants merely settle to the bottom of the flume. This method, however, may not be desirable because it adds to the moisture content of the fuel. Another method of fuel cleaning uses a strong magnet to rid the fuel of any ferrous particles as it is being conveyed to the hog or hammermill (9).

Sizing

Sizing is often a necessary step when the type boiler to be used requires a uniform particle size or when the raw material is of such a nonuniform distribution that a separation stage before hogging and hammermilling can greatly save on their power requirements. Hogging and hammermilling are then used as the secondary sizing stage.

Initial sizing can take place either at the logging/harvesting site or at the mill. One method, for use with a portable chipper, uses an auger to transport the material over screens to separate the chips into two piles. Smaller chips that have fallen through the screen will be in one pile, while the other pile will contain the larger material that merely passed over the screens.

Two common presizing methods for mill site use are disc screens and vibratory screen classifiers. The sizing disc screen is similar to those used for cleaning, except the interdisc spaces are usually larger, depending on the desired product. As with the cleaning disc screen, the larger material travels across the top surface, while the smaller particles pass between the rotating discs. Screen classifiers use vibration to agitate the material, permitting smaller particles to pass through the wire mesh, while larger particles are transported across it (9). Another sizing method is generally used in conjunction with a hog or hammermill. It utilizes a centrifugal action to separate out the finer particles while sending the larger pieces back for further processing (19).

Drying

There are many important reasons for the inclusion of a drying phase in the preparation of wood fuel. Among the most important are: (a) more efficient burning, since water does not have to be evaporated in the fire box before the energy is released; (b) the burner can be operated

at higher temperatures with less pollution and more rapid burning; (c) less excess air, since the more air present, the greater the heat lost with the flue gasses, (d) less weight, since dry particles weigh less and thus are more easily suspended; and (e) improvement in response and control of the burner (14).

The methods of moisture reduction are nearly as numerous as the reasons for doing it. The most common are: (a) transpirational or in-woods drying; (b) air drying after chipping or chunking; (c) pressing; (d) hog drying; (e) hot conveyors and (f) rotary drums.

Transpirational drying, or leaving the-felled trees in the woods for approximately 2 weeks before processing, has been found to reduce slash pine moisture content by up to 41% in the summer and up to 18% in the winter. This drying will not only help at the burning stage, but it could also prove beneficial in terms of reduced transportation costs due to reduced weight (11).

If stored under outside ambient air conditions with rain protection for a long period of time, wood will stabilize at about 16% moisture content (dry weight); thus air-drying storage methods may prove a feasible means of moisture-reduction (7). Sturos et al. (17) investigated the possibility that wood chunks, with their larger inner partical voids, might dry faster under ambient air conditions than chips. Their preliminary results suggest that this might indeed be true,

Pressing as a means of expelling fuel moisture has two advantages--it requires relatively little space; and it does not need a heat source. Its disadvantages are major, however--high maintenance, high power requirements, and limited moisture reduction capabilities (14).

Hot hogs, which can utilize boiler stack gasses as a heat source, actually combine the drying and size reduction processes. The major advantage of this method is that the grinding action is constantly exposing more wood surface area to be dried. This speeds the drying process and allows for more complete and uniform drying (14).

Hot conveyors, which can also use boiler stack gasses as a source of heat, have at least two disadvantages: First, low gas temperatures result in low moisture release rates; second, conveyors appear to have high maintenance costs while having a relatively low drying capacity (14).

Rotary drum driers appear to be the most popular method of moisture reduction at the boiler site for several reasons: (a) they can operate at higher temperatures, (b) they can effectively dry large quantities of high-moisture material, (c) they generally have low maintenance, and (d) they have a high retention time that allows for lower final moisture content (14).

Rotary drums are available in two basic forms--open center and center fill. As the name implies, open center drums have no inner center structure to aid in fuel dispersion and heat transfer. The drum merely rotates, mixing the material by means of vanes attached to the drum's

inner surface. Hot air enters with the fuel and pneumatically propels it through the drier (19).

Center fill rotary drums have the same pneumatic propulsion and rotational characteristics as the open center drum driers. Their center, however, contains various structures that aid in heat transfer and even mixing. These structures also allow for a greater fuel retention time than that of an open center dryer because they do not rely *only* on pneumatic conveying. All this combines to produce a more uniform drying than that produced by an open center drier (18).

SUMMARY

In summary, the choice of a processing system for preparation of fuel wood depends on the form and moisture content of the raw material and which combustion method will be used. The processing system should be composed of the most efficient and economical combination of size reduction, cleaning, drying, and sizing equipment possible with current technology.

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