PROCESSING AND ECONOMICS OF MIXED PAPER WASTE AS AN ENERGY SOURCE

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ABSTRACT

The processing of mixed paper waste into densified fuel and its subsequent thermal conversion can provide a biomass alternative energy source for various applications such as greenhouse heating and crop drying. The processing utilizes the unit operations of shredding, air classification, magnetic separation, and densification. A database has been developed to characterize the unit operation processing parameters for the fuel. Economic data for the processing system are used to evaluate overall system concepts. Results are presented in a manner that allows for interpretation with respect to local market prices.

INTRODUCTION

Waste paper is commonly classified as either bulk grade or high grade. Whereas the high grades are considered as pulp substitutes, the bulk grades are used in large quantities in recycled paper, paper board, and construction products, hence the designation "bulk" grade. The materials comprising bulk grades are corrugated, newspaper, and mixed paper waste (MPW). The MPW materials include a wide range of the lowest quality paper stock and consist of unsorted mixed paper obtained primarily from office buildings, commercial sources, printing establishments, and converting operations. Basically, MPW represents the lowest end of the recycled fiber spectrum. Thus, it is available in abundant quantities and has been historically difficult to market for recyclers [1, 2]. In fact, much MPW cannot be marketed, and therefore the collection rate of MPW could easily be expanded if new markets are found. This paper explores an undeveloped market for MPW—its use as an energy source.

MPW is an attractive energy source for several reasons. Unlike municipal solid waste, which also contains a high fiber fraction, MPW is relatively homogeneous and is free from putrescibles, metals, and other noncombustibles. Consequently, only minimal processing is required to convert it into a densified form of energy suitable for direct combustion or gasification. When processed into densified fuel, the heating value of the fuel is close to that of wood [1, 3]. In addition, the densified fuel has excellent storage characteristics, a low sulfur content, and low NO_x emissions when properly combusted [4].

The utilization of MPW as an alternative fuel would require some modifications to current equipment unless the existing system is coal fueled or wood fueled. An auxiliary unit such as a gasifier or a special furnace must be added to the existing system if it is gas fueled. For example, in the case of gas-fueled greenhouse heating, if the densified MPW fuel were gasified in an onsite gasifier, then the subsequent producer gas could be directly combusted in the existing burner and boiler tube furnace arrangement. Alternatively, the densified fuel could be directly combusted in a modern controlled furnace, and the hot combustion gases passed directly over the tube section of the existing boiler. Automatically stoked wood chip furnaces are ideally suited for the combustion of the fuel, particularly in the 1,000,000 Btu/hr (293 kW) range which is consistent with agricultural applications.

It has been estimated that in order to heat a 5000 ft^2 (465 m^2) greenhouse, 30 tons (27 t) of wood chips would be consumed annually with a savings of 5000 therms (105 MJ) of natural gas [5–7]. Our projections indicate that even with processing, the cost of densified MPW could be comparable to that of wood chips in many areas of the country. The resulting savings could be in the range of 30–40% of the cost of natural gas. To further aid the overall economics, the MPW fuel can be processed near the source of supply and transported in bulk carriers. In the following sections, consideration is given to the parameters governing the preparation of the feedstock, commercial processing scenarios, and system economics.

TABLE 1 RESULTS OF MIXED PAPER WASTE DENSIFICATION EXPERIMENTS

Secondary Shredder Characteristics	Moisture Content (%)[a]	Densifer Flow Rate (tons/hr)	Densifer Flow Rate (Mg/hr)	Approximate Percentage of Reject Pellets
0.75-inch (19.1 mm) bar gates	8	0.10	0.09	20
		0.20	0.18	20
		0.30	0.27	20(Jam)
	18	0.22	0.20	20
		0.33	0.30	Jam
	20	0.23	0.21	20
	22	0.12	0.11	20
		0.23	0.21	20
	24	0.12	0.11	0
		0.24	0.22	Jam
	26	0.24	0.22	20
	30	0.26	0.24	20
1.0-inch (25.4 mm) circular holes	8	0.20	0.18	5
	28	0.25	0.23	1
	28	0.50	0.45	1
		0.75	0.68	1
	38	0.86	0.78	1
		1.71	1.55	Jam

[a] Total moisture content

FEEDSTOCK PREPARATION

Experimental Studies

Typically, MPW is available either loose or baled when obtained from such sources as large commercial establishments, recycling operations, and paper brokers. However, the ideal form for the fuel in terms of transport, on-site storage, and thermal conversion is a densified form such as pellets, cubes, or briquettes. The problem becomes one of processing the MPW to remove major contaminants and to obtain the proper size distribution and moisture content for optimum densifier throughput.

To examine the feasibility of producing a densified fuel from mixed paper wastes, a series of tests was conducted at the University of California's (U.C.'s) Solid Waste Processing Laboratory located at U.C. Berkeley's Richmond Field Station. Various studies have indicated that although laboratory and commercial densification parameters differ from each other, the laboratory tests offer useful evaluations of the feasibility of biomass densification processes [4, 8]. Baled MPW was milled to two distinct size distributions having Rosin-Rammler characteristic sizes ranging between 0.5 and 1.0 in. (12.7 and 25.4 mm). A two-stage shredding procedure was used. The baled material was first passed through a 10 ton/hr (9.1 t/hr) Gruendler swing hammer mill having a 2 in. (50.8 mm) grate spacing. The shredded feedstock stream was then passed through an air classifier to remove any heavy inorganic contaminants that may have been present in the wastes. The final size distributions were obtained by using a fixed hammer mill manufactured by W-W Grinder, Inc. The secondary shredder was equipped with either 1.0 in. (25.4 mm) circular holes or a 0.75 in. (19.1 mm) horizontal bar grate below the hammers for the various test runs. A California pellet mill was used to densify the processed material to 1 in. (25.4 mm) diameter, 5 in. (127 mm) long pellets. The capacity of the pellet mill was rated at 2 tons/hr for animal feed. Tests were conducted at various moisture contents by controlling the water at the infeed to the pellet chamber. Test results, given in Table 1, indicate that the finer material produced by the 1 in. (25.4 mm) circular hole grates produced pellets of excellent integrity.

Both throughput and pellet integrity are sensitive to the moisture content. For example, at low moisture contents, when no water was added, the pellets became flakey and tended to lose their integrity with the subsequent generation of fines. When the moisture content exceeded approximately 30%, jamming occurred in the mill. At comparable moisture contents, only about half of the throughput that was obtained when densifying

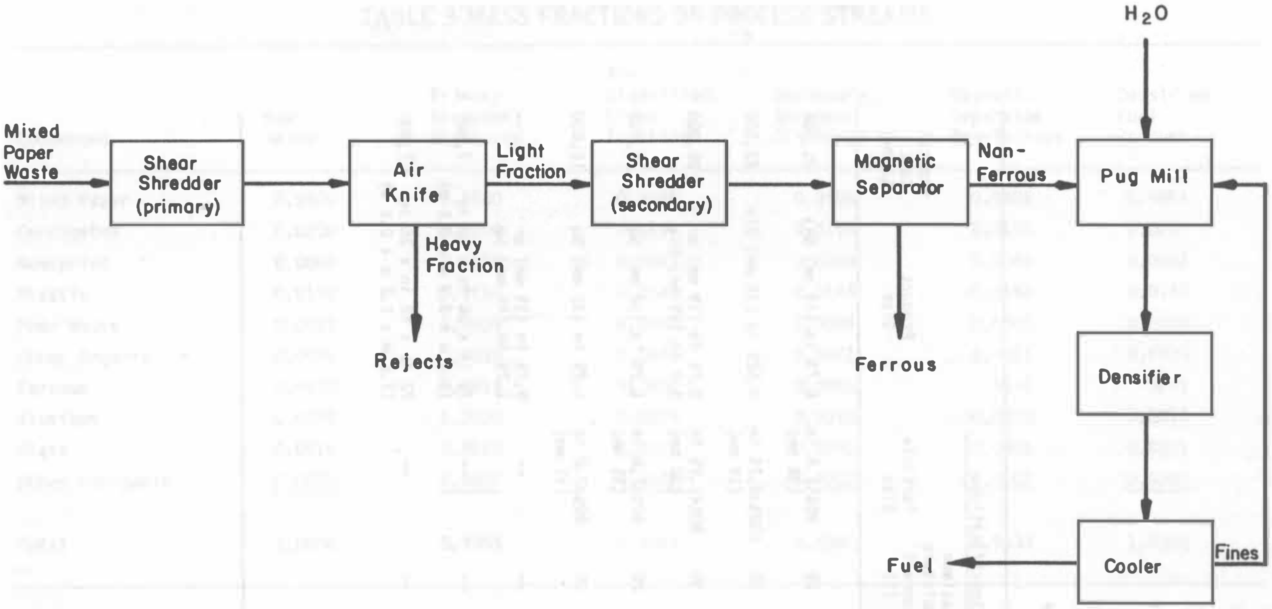

FIG. 1 MIXED PAPER WASTE PROCESSING SCHEME FOR DENSIFIED FUEL PRODUCTION

the smaller material produced with the 1.0 in. (24.4 mm) circular hole grate could be achieved when densifying the larger material produced with the 0.75 in. (19.1 mm) bar grate. It should be noted that although a larger grate opening in the shredder is desirable in terms of higher throughput, the subsequent particle size was not optimal for the particular shredder and densifier configuration. In a commercial application, the effective throughput of the shredder can be enhanced by trommeling the output to an optimum size for the particular densifier and by returning the oversized material to the shredder.

Commercial Processing Methodology

The composition of the MPW infeed has a bearing on the selection and arrangement of the processing unit operations. In general, guided by the laboratory studies, the feedstock must be conditioned to a particle size on the order of 1 in. (25 mm) or less and be free of noncombustibles prior to densification. Many different approaches are feasible. A versatile system, capable of dealing with metal and glass contamination as well as large-sized items, i.e., corrugrated, wood, etc., is shown in Fig. 1.

Although two stages of size reduction are shown, a single shredder capable of delivering the proper size distribution may be adequate. In the selection of the comminution system, consideration should be given to the use of a shear shredder instead of a conventional vertical or horizontal hammermill. These units operate at relatively low speeds and have a reversing or unjamming feature. Furthermore, requirements in terms of foundations and specific housings for explosion protection may be simpler. In addition, the operating and maintenance cost in terms of hammer replacement may also be more favorable for the processing of a predominantly paper feedstock.

In the system shown in Fig. 1, the shredded material from the primary shredder is passed over an air knife, a process which acts as a form of air classification. Here the heavy, typically noncombustible fraction is removed. A magnetic separator positioned above the shredder discharge conveyor will remove most of the remaining ferrous materials that were not discharged by the air knife.

A number of alternatives, such as briquetting, cubing, and pelletizing, are available for the densification system. Each of these methods uses a slightly different mechanism to densify the shredded feed. For example, in a briquetting press, a piston is used to force material through a single die. On the other hand, pelletizers and cubers utilize multiple hole dies which allow several units to be produced simultaneously. Because of the differences in creating the densified product, the subsequent characteristics, power consumption, and capital costs vary. A comparison of principal parameters is given in Table 2. The manner in which the densified fuel is combusted will also influence the mode of densification. For example, since the density of bri-

TABLE 2 DENSIFIER CHARACTERISTICS[a]

Equipment Type	Manufacturer	Throughput Capacity[b] (tons/hr)	Throughput Capacity[b] (Mg/hr)	Installed Horsepower	Power Consumption (kWh/ton)	Power Consumption (kWh/Mg)	Feedstock Specifications: Optimum Moisture Content (%)	Feedstock Specifications: Maximum Moisture Content (%)	Feedstock Specifications: Particle Size	Product Size	Capital Cost ($/TPH)
Pellet Mill	Simon-Barrow	6	5.5	300	40	44	18-20	25	95%<1.5 in (38 mm)	0.75 in (19 mm) Dia	21,100
	Sprout-Waldron	4-5	3.6-4.5	300	--	--	15-20	30	100%<0.75 in (19 mm)	0.625 in (16 mm) Dia	22,100
	California Pellet Mill	5	4.5	300	30	33	10-15	30	90%<1.25 in (32 mm)	0.75 in (19 mm) or 1.0 in (25 mm) Dia	20,000
Cuber	Warren & Baerg	8-10	7.3-9.1	200	14	15	12-18	20	90%<2.0 in (51 mm)	1.25 in (32 mm) Sq	12,700
	Papakube	6-10	5.5-9.1	150	11	12	13	20	90%<2.0 in (51 mm)	1.25 in (32 mm) Sq	12,600
	Lundell	3-5	2.7-4.5	150	15-26	17-29	12-15	--	--	0.75 in (19 mm) or 1.75 in (44 mm) Sq	--
Baler	Balemaster	4.5	4.1	25	--	--	--	--	--	72 in x 36 in x 30 in (1.8 m x 0.9 m x 0.8 m)	7,800
	International Baler Corp.	3-5	2.7-4.5	30	--	--	--	--	--	72 in x 48 in x 36 in (1.8 m x 1.2 m x 0.9 m)	7,800

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[a] Derived from reference [4].

[b] Capacity of equipment for which characteristics are quoted.

TABLE 3 MASS FRACTIONS OF PROCESS STREAMS

Component	Raw Waste	Primary Shredder Discharge	Air Classified Light Fraction	Secondary Shredder Discharge	Magnetic Separator Non-ferrous	Densified Fuel Product
Mixed Paper	0.9500	0.9500	0.9405	0.9405	0.9405	0.9851
Corrugated	0.0200	0.0200	0.0198	0.0198	0.0198	0.0207
Newsprint	0.0050	0.0050	0.0049	0.0049	0.0049	0.0052
Plastic	0.0150	0.0150	0.0148	0.0148	0.0148	0.0148
Food Waste	0.0010	0.0009	0.0006	0.0005	0.0005	0.0006
Other Organic	0.0030	0.0030	0.0021	0.0021	0.0021	0.0023
Ferrous	0.0010	0.0010	0.0001	0.0001	3E-5	3E-5
Aluminum	0.0020	0.0020	0.0010	0.0010	0.0010	0.0010
Glass	0.0010	0.0010	0.0001	0.0001	0.0001	0.0001
Other Inorganic	0.0020	0.0020	0.0002	0.0002	0.0002	0.0002
Total	1.0000	0.9999	0.9841	0.9840	0.9839	1.0300

quettes is about 20% greater than cubes or pellets, the combustion time for similar size units would be longer. Consequently, the residence time in the combustor would be a consideration in selecting the densification mode and configuration of the final densified product. The reliability of the equipment, i.e., performance track record in the field, die wear, and overall maintenance are important considerations for selecting a particular densifier for the shredded paper waste feed stock.

It is usually necessary to adjust the moisture content of the shredded material prior to densification. Although a separate mixing operation for combining water with the material is designated on the process flow sheet, in some cases this operation is an integral part of the densification equipment. For example, liquid spray and a mixing screw can be part of a pellet mill. The temperature of the densified material is increased by as much as 35–55°F (20–30°C) by the time it exits the densifier. Consequently, it is necessary to use a cooler or to construct the removal conveyor in a manner that allows the pellets or cubes to cool to near ambient temperature prior to storage, loading, or bagging. If the removal conveyor is constructed with a perforated belt, then any fines or broken pellets can be returned for redensification. During the cooling period, the pellets will have time to cure.

The processing scenario depicted in Fig. 1 was analyzed by means of computer models for the unit operations used. The computer models are based upon: *(a)* direct waste processing experience; *(b)* field testing of waste processing equipment at various resource recovery facilities; and *(c)* waste processing information reported in the literature. The models serve to predict the output of the unit processes employed in a waste processing system based upon the inputs to each process. The mass fractions of the simulated process streams are given in Table 3. The composition of the raw waste stream was derived from an example of a contaminated MPW feedstock from office buildings. The feedstock composition varies greatly, of course, with the source of the waste. The properties calculated with the computer model for the various streams are given in Table 4.

SYSTEM ECONOMICS

A computer model was also developed for the economics of the MPW processing system. The cost models are based upon several sources, including: *(a)* information reported by waste processing facilities; *(b)* the waste processing experience of the authors; *(c)* information obtained from equipment vendors; and *(d)* information supplied by contractors. The model used in this paper was based on a 100 tons/day (91 t/day) operation for the system shown in Fig. 1. It was assumed that the facility operated 5 days/week with a single processing shift. Some maintenance work would be performed on a second shift.

The estimates of capital and operation and maintenance costs are given in Table 5. The capital costs are estimated to be approximately $3,000,000. The costs given for processing equipment, the largest cost category, are the installed costs. These include costs for shipping, taxes, additional foundation work, motor controls, and installation. The total building area was sized at approximately 34,000 ft^2 (3160 m^2) and in-

TABLE 4 PROPERTIES OF PROCESS STREAMS

Unit Process	Moisture Content (%)	Oven-Dry Ash Content (%)	Oven-Dry Heating Value		As-Received Heating Value	
			(Btu/lb)	(kJ/kg)	(Btu/lb)	(kJ/kg)
Raw Waste	7.89	8.25	7,843	18,230	7,224	16,791
Primary Shredder	7.88	8.25	7,843	18,230	7,225	16,794
Air-Classified Light Fraction	7.90	7.79	7,882	18,321	7,259	16,873
Secondary Shredder	7.90	7.79	7,882	18,321	7,260	16,875
Magnetic Separator	7.90	7.79	7,883	18,323	7,261	16,877
Pug Mill	20.00	7.79	7,883	18,323	6,306	14,658
Densifier/Cooler	12.00	7.79	7,883	18,323	6,937	16,124

cludes receiving, processing, storage, maintenance (shop), and office areas.

The annual operation and maintenance costs were estimated at approximately $722,000. The largest operation and maintenance cost is labor. It was assumed that the facility would be operated by an eight person staff, which would consist of one plant manager, one foreman, one heavy equipment operator, two mechanics, two laborers, and one secretary. The other major costs are for maintenance and electrical power. Electric rates were assumed to be $0.06/kW·h.

There are two sources of revenue for the operation, namely, the sale of the fuel product and the tipping fee (i.e., disposal fee). Pricing of these revenue sources varies greatly with local conditions. Therefore, the evaluation of the system economics has been formulated in a manner that allows for interpretation with respect to local market prices. If total unit costs are known, then by fixing one unit revenue, the other unit revenue that is required to break even with costs can be determined.

Total unit costs for the 100 tons/day facility were based upon the amortized capital costs (including financing costs) and the annual operation and maintenance costs. A 20 year life and 10% financing were assumed for the facility.

Figure 2 depicts the breakeven cost of producing an MPW fuel as a function of tipping fees and fuel prices. The figure is based upon the results of the computer model simulations with fixed unit revenues. Both positive and negative values are shown on the scale for tipping fees. A positive value represents a fee charged for disposal of the waste at the facility; a negative value represents a price paid for the waste. The vertical scales indicate fuel prices FOB the plant. The fuel price is given in units of dollars per dry ton in the left-hand scale and in units of dollars per million Btu's in the right-hand scale. The conversion between the two fuel price scales is based on an assumed dry heating value of 7800 Btu's/lb (18,100 kJ/kg).

TABLE 5 COST ESTIMATES FOR A 100 ton/day MIXED PAPER WASTE PROCESSING SYSTEM

Capital Costs	
Buildings and Site Preparation	$ 659,000
Processing Equipment	1,484,000
Rolling Stock	90,000
Miscellaneous Equipment	47,000
Engineering	226,000
Startup	20,000
Contingency	376,000
Total	$2,902,000
Annual Operation and Maintenance Costs	
Labor	$300,000
Maintenance	198,000
Fuel	23,000
Electrical Power	115,000
Supplies	2,000
Residue Disposal	26,000
Insurance	45,000
Miscellaneous	13,000
Total	$722,000

The following are examples of how Fig. 2 can be used. If the local market price that can be obtained for the fuel product is $30.00/dry ton (equivalent is $1.92/MMBtu), then a tipping fee of approximately $13.90/ton would be required in order to break even with costs. Alternatively, if no tipping fee was charged, then it would be necessary to obtain a fuel price of $45.50/dry ton ($2.92/MMBtu) in order to break even.

At the present time, an MPW fuel processing facility may not prove economically feasible in all communities. However, Fig. 2 indicates that such a facility may already be feasible in certain parts of the country where existing tipping fees and fuel prices make an MPW fuel processing facility an attractive alternative. Furthermore, it is anticipated that tipping fees will rise at a faster rate than the capital and operating costs incurred for an MPW fuel processing facility. Thus, the applicability of this waste management alternative may broaden with time.

From the fuel user's perspective, the approach also has appeal. As discussed earlier, agricultural applications such as greenhouse heating and crop drying hold particular promise. Commercial gas prices averaged $5.53/MMBtu in 1984 and ranged from $4.86/MMBtu to $6.91/MMBtu in various regions of the country [9]. In addition, many commercial users are

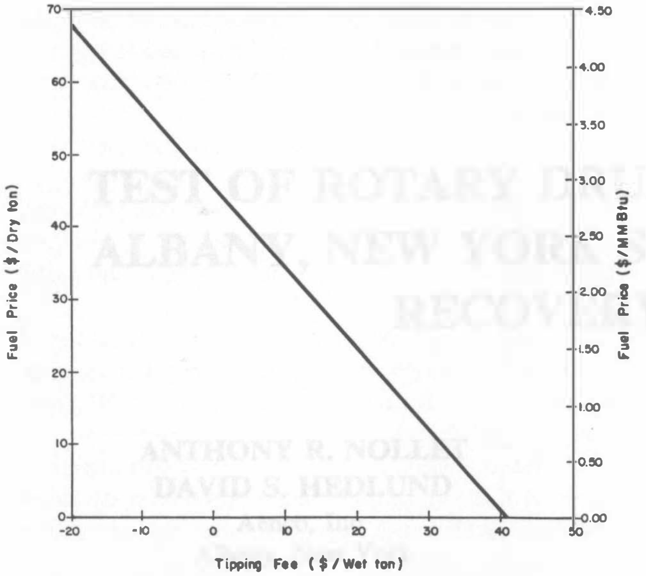

FIG. 2 BREAKEVEN COST OF MIXED PAPER WASTE PROCESSING AS A FUNCTION OF FUEL PRICES AND TIPPING FEES

considered by utilities to be on interruptable service in cases of gas shortages. This risk could be avoided with the conversion to a solid fuel system.

The processing of mixed paper waste into a densified fuel represents an undeveloped market for this material, which has a history of poor marketability. Evaluations of processing requirements and system economics indicate that this approach is indeed a viable waste management alternative.

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