Technical and economic feasibility of briquetting mill sludge for boiler fuel

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ABSTRACT *The use of briquetted sludge for fuel is an alternative to the current practice of landfill disposal. Sludge is typically less than 1% sulfur and has a heating value of more than 6000 Btu/o.d. lb. The resulting briquettes, when dried to at least 80% solids, have high compressive strength and abrasion resistance.*

A sludge briquetting system to handle 42 o.d. tons/day will reduce landfill by 47,000 tons/year and return a 5-year ROI of 35% on approximately $1 million of investment.

KEYWORDS
Energy
Fuels
Sludge
Waste management

Pulp and paper companies produce large quantities of sludge each day in their waste treatment processes (*1*). Currently, this sludge is used for landfills, but the expense is considerable. In addition to the increasing costs, future considerations of landfill disposal include the potential difficulty of finding suitable sites and the likely tightening of regulations governing solid waste disposal. A process that could convert the sludge to a form easily burned in a hog fuel boiler would minimize landfill disposal costs and would simultaneously satisfy some of the current and future fuel requirements.

Agglomeration followed by the burning of pulp and paper sludge is not a totally novel process. International Paper, for example, successfully started burning pellets at its Pine Bluff, Ark., mill in December 1982 (*2*). Compacting the sludge to form large-sized briquettes, however, has apparently not been attempted elsewhere.

Here, we summarize the physical and chemical characteristics of one particular sludge and the resulting briquettes. We also provide a preliminary process design and estimate the economic feasibility of installing and operating this process.

Process background

The nature of the sludge

In a typical kraft process, sludge is produced by the treatment of the waste water from the papermaking operations and from the spent liquor spills from the pulping steps. The waste treatment process, for the site we considered, produces a sludge that is 80% primary sludge and 20% secondary sludge on a weight basis, or 50% each on a volume basis. As it exits from the waste treatment, the sludge varies in solids content depending upon the specific processes. Various types of dewatering equipment typically increase the solids content to 20-30%.

The sludge is a fibrous material, consisting largely of very short fibers or other unusable wood fragments and excess microorganisms from the activated sludge treatment process. In addition, it contains filler materials that were not retained in the papermaking steps. Though the exact composition will vary with the particular product being manufactured at that time and other operating parameters, an average composition in terms of metals, nitrogen, and sulfur is presented in **Table I**. For comparison purposes, the composition of municipal sludge and typical paper mill sludge (*1*) are also included. Sludge A is the experimental material for this study.

Though sludge is high in aluminum and calcium, there are no metals in large concentrations that could create undesirable environmental effects, that would hinder combustion, or that would prevent disposal of the ash.

The sulfur content (approximately 0.5%) is lower than many "low-sulfur" coals and should create no serious emissions problems. Because of its high concentration, the calcium will likely bind some of the sulfur and further reduce the SO_2 emissions.

The nitrogen content (1%), though low compared to municipal sludge, is high enough to result in significant NO_x emissions if the sludge is burned under excess oxygen conditions. Briquetting should help this problem because fuel nitrogen conversion in stoker beds is lower than in suspension-phase burning.

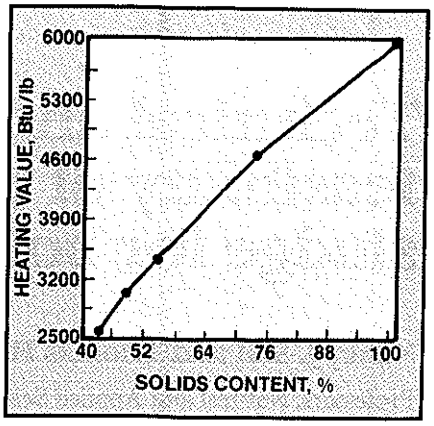
Calorimetry measurements were made on Sludge A, and the results are in **Fig. 1**. Again, these values are only typical, and they vary depending on the sludge composition at the time of sampling.

I. Sludge composition, percentage of dry weight

	54 Pulp & Paper Mills*		Sludge A		
Component	Range	Median	Range	Median	Municipal Median
N	0.11 - 5.90	0.85	0.81 - 1.31	1.06	3.3
K	0.012 - 1.00	0.22	0.20 - 0.23	0.21	0.3
Ca	0.028 - 21.0	1.40	2.81 - 3.49	3.15	3.9
Mg	0.02 - 1.90	0.155	0.55 - 0.82	0.69	0.45
S	0.02 - 2.00	0.468	0.48 - 0.62	0.55	1.10
Al	0.0590 - 8.90	1.34	2.1246 - 2.8500	2.49	0.40
As	$<7\times10^{-6}$ - 0.00083	0.00012	...	0.00862	0.0010
Cd	$<9\times10^{-6}$ - 0.0056	0.00012	...	0.00053	0.0015
Hg	9×10^{-8} - 0.000352	3.5×10^{-5}	...	<0.00032	0.0006
Na	0.0300 - 6.6700	0.22	0.0779 - 0.0880	0.0830	0.24
Pb	$<5\times10^{-6}$ - 0.0880	0.0028	...	0.00144	0.050
Fe	0.00971 - 1.08	0.154	0.6987 - 1.1190	0.9089	0.17
Total incombustible			15 - 30	0.22	

*Blosser (*1*).

1. Sludge heating value



Sludge briquettes

The sludge was briquetted at the University of Wisconsin-Green Bay pilot plant facility, located at Feeco International. The process in the pilot plant is a batch operation, but the results should be translatable to a continuous operation.

The sludge was dried (at about 175°C) in a large forced-draft oven and mixed to assure a more uniform water content and to produce a material of balls approximately 0.64–1.3 cm in diameter. In this form, the sludge was fed to a Bepex model CS briquetter. The pressure on the rolls, the size of pockets which determine the briquette size, and the sludge moisture content were variable.

For combustion process reasons, efforts concentrated on relatively large sludge briquettes, with a volume of 50 cm^3. The weight of the briquettes varied with water content, ranging from about 25 g to about 65 g at 40% solids. The larger size and weight assured that the briquettes fall to the bottom of the hog boiler during firing.

To determine the optimum sludge moisture for briquetting, briquettes were made from sludge at various moisture levels (25–55% solids content) and at three briquetting gauge pressures (1000, 2000, and 3000 lb/in.^{2}—or 26,895, 13,290, and 20,685 kPa). The green briquettes were immediately tested for compressive strength, and the results are shown in **Fig. 2**. The optimum moisture content for briquetting appears to be 40% solids content. Though the higher briquetting pressure of 3000 lb/in.^{2} produces stronger briquettes, it may be economical to briquette at lower pressures to decrease abrasion on the rolls.

At this moisture content of 40% solids, the sludge does not tend to stick to the briquetting wheels, so no release agent is needed. It might help to have a system to occasionally rap the wheels to assure no sludge is building up in the system, depending on the exact nature of the sludge, but this was not necessary for the particular samples with which we were working.

The green briquettes are not sufficiently durable to be roughly handled, so it is necessary to dry them after formation. This drying will of course increase the as-fired heating value in the burning step, as noted in Fig. 1. To dry the briquettes completely before firing would take too much time. Therefore, an optimum balance must be reached at which the briquettes are strong enough and have a large available heat content yet do not require excessive drying. To determine this optimum point, briquettes were formed from sludge at 40% solids contents. These briquettes were then dried in a 177°C forced-draft oven for various lengths of time. **Figure 3** illustrates the drying rate, and **Fig. 4** illustrates the corresponding increase in compressive strength with drying.

The compressive strength of the briquettes is a useful measure of how well the briquettes will withstand being stored in large piles. However, their resistance to abrasion is a better measure of how they will withstand the forces normally experienced while they are being transported. To determine this resistance to abrasion, four sludge briquettes were shaken automatically for various periods of time in a cylindrical metal container 15.5 cm in diameter. The briquettes are relatively resistant to abrasion, losing about 5% of their initial weight in the first hour and 13% in 8 h.

Another problem with moist briquettes is the potential for deterioration caused by microbial growth. Green briquettes rapidly become moldy under warm, moist conditions. No problems will occur if the sludge briquettes are burned soon after formation, or if they are spread out and allowed to air dry. However, if they are to be stored longer than a week or two in nondrying conditions, it would be advisable to dry them first.

Because of the need for increased strength and the need to curtail microbial growth, the briquettes should be dried to 80% solids content if they are to be stored for any length of time. If they are to be burned immediately, less drying is permissible from a microbial deterioration perspective. However, the heating value decreases when they are burned moist, and this encourages drying with waste flue gas.

Drying the sludge creates an odor problem. Consequently, drying must be conducted in an enclosed area, using proper environmental controls.

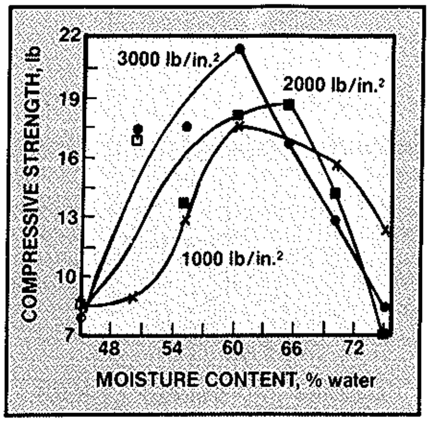
Once the briquettes are dried, they are quite hydrophobic. They retain their shape, though they become soft after several weeks of storage under water. Short periods of contact with water such as rain, for example, should not have a major detrimental effect on them.

Process design and evaluation

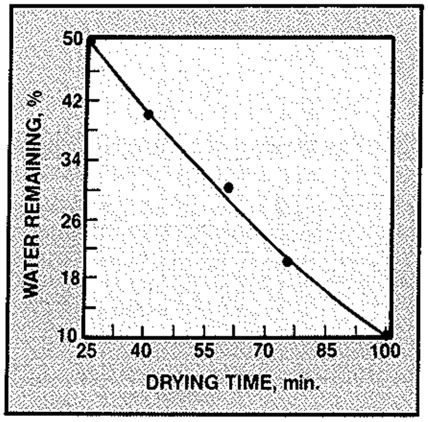
The following procedure was used for the design and economic evaluation of the sludge briquetting and burning process:

1. Determine the optimum physical characteristics for the briquettes (strength, microbial stability, heating value) and the corresponding process conditions.
2. Design an appropriate flowsheet,

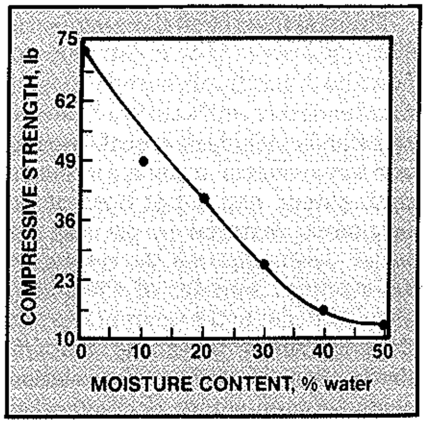
2. Strengths of briquettes formed at various moisture contents.



3. Briquette drying time



4. Strength vs. moisture content



including the type of equipment most feasible for each step in the process.

3. Estimate the costs from vendor information using estimating techniques (*3*) including the Marshall and Swift Index.

4. Determine the profitability for replacing a portion of the bark with sludge and for selling the excess bark.

Process constraints

For the purpose of the economic evaluation, the landfill sludge is estimated to be available at 20–30% solids, at a rate of 42 o.d. tons/day. Approximately 15–30% of this material is ash. Primary sludge tends to be higher in ash (27%), and normal mixed sludge is lower (22–23%).

Figure 5 is the flowsheet that was developed for this process. **Table II** indicates the mass and energy balance values which correspond to the major streams. In these balances, 100% yield of solids is assumed through the screw press, briquetter, conveyor dryer, etc. Undoubtedly, there will be some loss at each step, but internal recycling, such as sending the excess water back to waste treatment, should minimize the overall solids loss.

As the figure shows, there are several options available. If necessary, the sludge can be sent to the landfill after the belt press. The briquettes can be dried and fed directly to the hog fuel boiler, or they can be placed into storage for later combustion. In this latter case, though it probably would be desirable to protect them to prevent extensive soaking due to rain, a totally enclosed area is not necessary.

Equipment costs

There are three major pieces of equipment to be purchased for this process:

1. Equipment to increase the solids content from 30% to 40% prior to briquetting
2. A briquetting machine
3. Equipment to dry the green briquettes from 40% solids to 80% solids.

Screw press

Because of its slow heat drying rate, it is much easier and more economical to initially increase the solids contents of the raw sludge by some mechanical means. If it exits the waste treatment at 20–30% solids, the sludge is too moist for efficient briquetting. We therefore recommend a second stage of water extraction by means of a screw press. To ensure that the feed portion of the press does not become plugged, a maximum of 20% solids contents in the waste treatment exit stream is recommended. A variety of types of screw presses are commercially available. We chose to use data for an 18-in. horizontal press in our calculations. This press should be capable of increasing the solids content to 38–42%. The estimated equipment cost is $138,600.

Briquetting machine

The pilot plant work was conducted on a Bepex model CS briquetter. This briquetter has two horizontally mounted wheels. Vertically mounted wheels are generally preferred, however, if moisture in the material is a potential problem. For this reason, we used the specifications for a vertically mounted system. The estimated equipment cost is $106,000.

Conveyor dryer

Most paper companies, particularly those with integrated pulping capability, have waste heat available. We assumed that an adequate amount of flue gas (a minimum of 60,000 ft^3/min) at 175°C and 26% moisture was available from the recovery boiler. This heat can be used to dry the briquettes in either a tray or conveyor dryer. The capital investment will likely be less with a tray dryer, but this advantage is soon lost as a result of the increased labor costs, particularly when a large volume of sludge must be dried. For this reason, we recommend a conveyor dryer.

The conveyor dryer cost estimate of $250,000 used in these calculations was for a single-pass system. Such a system would need to be 8–10 ft wide and 100 ft long. A multiple-pass conveyor dryer system is also an option. Though the capital cost for the multiple-pass system is almost twice that of a single-pass system ($410,000 plus an additional $40,000 for a cooler), the physical size is much smaller. A five-pass (5-belt) conveyor would be approximately 9 ft high, 10 ft wide, and 27 ft long. The cooler would add approximately 11 ft to the length.

Additional costs

Engineering costs including electrical, piping, installation, and controls are estimated to be about $400,000. Other conveyors (100 ft estimated) would add $30,000.

Odor control can be accomplished by enclosing, especially the conveyor dryer. Ductwork can transport the exhaust air to the boiler air intake for odor removal. It is assumed that this dryer and the remainder of the briquetting process can be located in a building already in existence, so no cost estimates are included for foundations, enclosures, or air handling systems. If construction is necessary, these costs might add another $100,000, or about 10% of the purchased equipment cost.

The total fixed capital investment of $925,000 is as good as an estimate can be without specific drying and burning tests made on a mill's sludge. The next step should include pilot-scale production of briquettes, using a continuous feed system, and a test burn of the briquetted material in the hog fuel boiler. Assuming that the results are satisfactory, samples of the sludge should be sent to the appropriate vendors for screw press and conveyor dryer tests, to confirm the relationships between sludge characteristics and process equipment.

Operating costs

The estimated yearly operating costs are based on continuous operation 24 h/day, 360 days/year.

The power costs were obtained from Wisconsin Public Service (Green Bay) and are indicative of costs for a large-scale user. The peak and off-peak rates were simply averaged to give a value of $0.41 kW/h. The demand charges are $4.35/kW (per month). The total connected hp is estimated to be 300, the kW 223, the demand charge $11,600, the time charge $79,000.

One additional person per shift would be required to monitor the entire process at a loaded hourly cost of $16.00. The labor costs are therefore $137,700 annually.

Maintenance was estimated to be 6% of the fixed capital, or $55,500 per year.

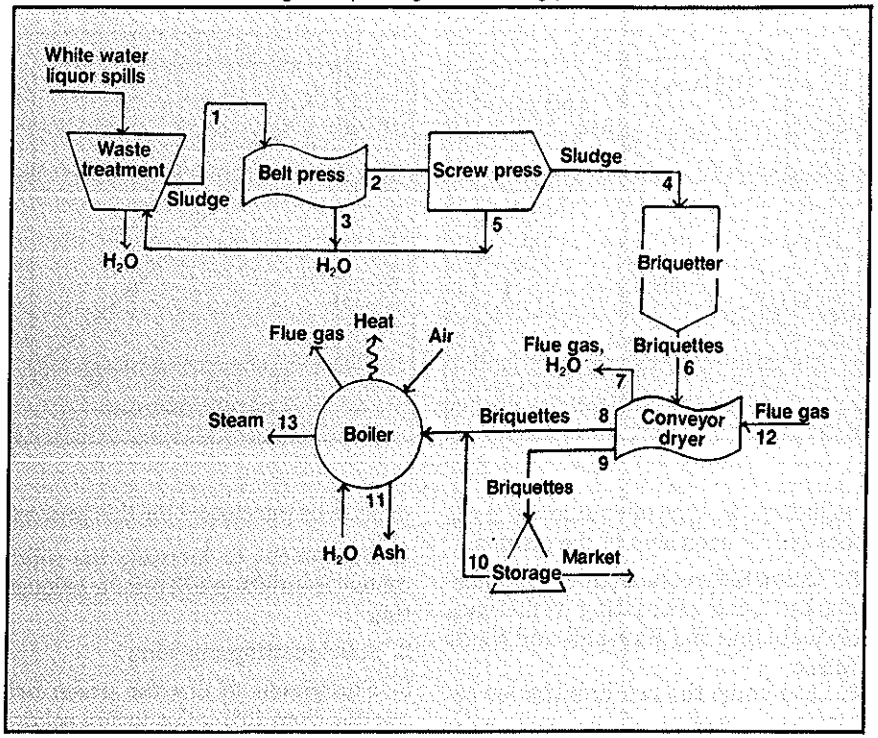
The resulting total operating costs are estimated to be $283,000/year.

Savings

The sludge is assumed to be burned in the existing hog fuel boiler, replacing a portion of the bark currently used. The bark is assumed to have a heating value of 4500 Btu/lb at 50% moisture (*4*). The amount of bark that could be replaced is that amount that would provide an equal amount of energy to the energy obtainable by burning 100% of the sludge generated. It is realistic to assume that the bark can be sold at the cost of hauling and handling. Under these circumstances, $939,000 can be saved annually in reduced disposal costs.

If mill circumstances are such that sludge briquettes actually replace purchased fuels of higher value, the economic return is substantially greater.

5. Flowsheet for the sludge briquetting and burning process.



II. Mass and energy balances

Stream no.	Nature	Flow rate, tons/day	Available energy, 10^6 Btu/day
1	Sludge (2.9% solids)		
	Solids	42	...
	Water	1406	...
2	Sludge (20% solids)		
	Solids	42	...
	Water	168	...
3	Waste water	1238	...
4	Sludge (40% solids)		
	Solids	42	...
	Water	63	...
5	Waste water	105	...
6	Briquettes		
	Solids	42	...
	Water	63	...
7[a]	Water vapor	52.5	120
	R. boiler flue gas	2040	...
8–10	Briquettes		
	Solids	42	428
	Water	10.5	...
11	Ash (22% o.d. solids)	9.2	...
12	Incoming flue gas	2040	240
13[b]	Steam from sludge fuel	114	272

[a]50% transfer efficiency assumed.
[b]60% transfer efficiency assumed.

Profitability evaluation

In these ROI calculations, the project was assumed to have a lifetime of only 5 years, and the salvage value was assumed to be 0. A straight line depreciation over the 5-year period was used, and a 50% tax rate was assumed. Annual operating costs are about $283,000, and savings from landfill costs are $939,000. Under the cash flow, salvage, and project lifetime conditions assumed, the return on the investment is greater than 35% (**Table III**).

III. Savings incurred by sludge burning

Landfill costs for sludge as is	
tons of sludge/year	50,400
$/cubic yard[a]	12.50
$/ton	19.00
$/year	957,600
Landfill costs for sludge if burned at 22% ash	
tons of ash/year	3326
$/year	63,200
Savings by landfilling sludge ash	
tons/year not landfilled	47,070
$/year	894,000
Sludge available as briquettes	
tons/day (80% solids)	52.5
tons/year (80% solids)	18,900
Bark replaced by sludge	
Btu/lb of sludge (80% solids)	5090
Btu/lb of bark (50% solids)	4500
Million Btu/year from sludge	192,400
equivalent tons/year of bark	21,380
Savings by not landfilling bark ash	
tons of bark ash/year	2352
$/year	44,680
Total savings	
total tons not landfilled	48,400
$/year	939,000

[a]Includes both hauling and incremental landfill capital investment, assuming a 50-year lifetime.

Comparisons to other sludge disposal methods

As mentioned, most mills currently dispose of sludge by landfill. Though options such as land spreading for silvicultural or agricultural purposes are possible (*1*), these uses have been restricted in many states because of environmental questions concerning dioxin and heavy metal accumulation. Combustion, therefore, offers the only potential large-scale use at this time. Other combustion methods have been developed, including the pellets used at the International Paper mill (*2*) and fluidized bed combustion of loose, dry, particulate sludge.

The mill from which we obtained the major portion of the sludge we used had previously attempted to extrude the material, but the attempt was unsuccessful. Not all sludges are suitable for forming pellets. In addition, the smaller, lighter pellets would not have the advantage of dropping to the bottom of the hog fuel boiler during combustion. On the other hand, fluidized bed combustion requires a completely different technology in which replacing some of the bark currently burned by sludge cannot be as easily or economically implemented.

No technical difficulties are foreseen with the sludge briquetting process. There should be no difficulty drying the sludge and the briquettes appropriately for burning. The screw press should provide sufficient sludge moisture control to assure good briquetting, with no significant sticking of the sludge to the briquetting wheels.

The burning characteristics of each particular sludge must be evaluated, however. Potential technical difficulties might be the slagging of ash and the fouling of surfaces. Excessive amounts of clay, in particular, may create difficulties in the boiler which must be monitored. Finally, the potential difficulty of finding suitable landfill sites in the future and the likelihood of a tightening of regulations governing land disposal also support the installation of this process.

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