CONSIDERATIONS USING SLUDGE AS A FUEL

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ABSTRACT

The pulp and paper industry is facing a serious and growing problem with sludge disposal. One option many companies are investigating is the burning of sludge in a boiler, which inerts the ash and reduces the amount of material to be landfilled. The incremental benefit with this option is the steam generated from burning sludge. Although this steam generation is low compared to burning bark or fossil fuels, in many cases, there is still a net steam production which offsets some fossil fuel consumption.

This paper presents combustion technologies that can burn sludge ranging from small slip streams co-fired with bark to 100% dedicated sludge burners. The basis of this paper is an examination of sludge characteristics and how they impact combustion. Understanding these characteristics allows plant operators to make the proper decision on applying the correct technology for their plant requirements.

INTRODUCTION

Combustion technologies have evolved over the decades to meet constantly changing demands. Several decades ago, "Good" fuels were readily available and comparatively inexpensive; consequently, combustion technologies were quite simple. As the demands changed so did combustion technologies. The single greatest demand for change has been in relation to environmental issues. New clean air standards have affected furnace sizes, burner designs, backend equipment and much more. Continuation of this evolutionary process will continue into the next century with such technologies as Integrated Gasification Combined Cycle, Pressurized Fluidized Bed Combustion, and other advanced systems.

Another influence on combustion technology is the desire to burn wastes which were once simply thrown away. The list of such wastes is almost endless as are the reasons for wanting to burn them, but there is one common denominator which characterizes these wastes: they are difficult to burn due to their high moisture and ash contents, low heating values and difficulties in preparation and handling.

The pulp and paper industry produces a waste sludge stream that is typically landfilled. One option for sludge disposal is to burn it in a boiler. Unfortunately, sludge falls into the category of "difficult to burn". This paper explains what "difficult to burn" means and how it influences combustion technology choices for existing boiler modifications or new boilers.

TRAVELLING GRATE COMBUSTION PROCESS

One of the most common inquiries for burning sludge is to co-fire sludge with bark using an existing power boiler with a travelling grate. This combustion technology has its limitations when it comes to burning sludge, because sludge is more difficult to burn than bark. Before examining the elements that make sludge difficult to burn, it is important to review the key elements that make bark-only firing successful using this combustion technology.

In any combustion process, time, temperature and turbulence drive the process. This means the fuel particle must absorb heat to elevate its temperature to the ignition point. Air which supplies oxygen for the combustion process must surround the fuel. Oxygen availability sets the rate of combustion. To make the combustion rate rapid, good mixing (turbulence) assures a continuous supply of oxygen to the burning (oxidizing) fuel particle. Finally, there must be adequate time for the fuel particle to completely combust.

For the travelling grate power boiler, the combustion process depends on:

- A uniform layer of fuel on the grate, and good air distribution for mixing (turbulence)
- A source of heat to raise the fuel particle temperature to ignition (temperature)
- An optimum grate speed for complete combustion (time)

Proper fuel/air distribution and grate speed can be adjusted during operation. However, the operator has little control over combustion zone temperature. The elements which determine the combustion zone temperature are set by the boiler design, with the intent of maximizing this temperature for good combustion.

To understand why it is important to maximize the combustion zone temperature, consider combustion on the grate from a fuel particle's perspective. When the boiler is operating, a constant flow of new fuel is added to the combustion process. These new fuel particles land on the grate and are surrounded by air and other burning fuel particles. For the fuel particle to reach its ignition temperature, heat must be absorbed from the surroundings. The sources of heat are adjacent burning fuel particles, hot combustion air, and combustibles burning above the grate. Unless the particle comes in direct contact with a burning particle, the primary mode of heat transfer to elevate the new fuel particle temperature is radiation. Radiant heat transfer is a direct function of temperature:

$$Q = f\,(T_2^4 - T_1^4)$$

where T_2 = combustion zone temperature
T_1 = fuel particle temperature

Since the temperatures are raised to the fourth power, even small decreases in combustion zone temperature can result in large decreases in heat transfer to the fuel particle which lowers its temperature. A decrease in the fuel particle temperature requires the residence time to increase for complete combustion; that is, the plan heat release would have to be lowered. To ensure high heat transfer rates to quickly ignite the new fuel particle, the combustion zone temperature is maximized by balancing the effects of plan heat release rate and combustion air temperature for a given fuel.

Combustion temperature is a key element in combusting fuel. The higher the temperature, the faster the chemical reaction (burning) takes place. In addition to plan heat release rate and combustion air temperature, a change in the fuel moisture can negatively influence the combustion temperature.

To illustrate this effect, Figure 1 shows a simplified combustion process. Fuel's chemical heat and air's sensible heat combine to yield a flue gas at some temperature "T". The heat in the flue gas is both sensible and latent heat. For a constant heat input process, as the moisture in the fuel increases, the latent heat of evaporation increases and the sensible heat decreases. By definition, for a decrease in sensible heat, the temperature must drop.

To relate moisture's evaporation effect on combustion temperature in a bark-fired boiler, Figure 2 is a graph showing the relationship of bark moisture, combustion air temperature, and adiabatic combustion temperature. The adiabatic temperature is combustion of a fuel and the resultant temperature with no heat transfer to the enclosure. Analytically, adiabatic temperature is the total heat (including air sensible heat), less the latent heat of evaporation, and divided by the flue gas weight which is an enthalpy that can be converted to a temperature by the relationship:

$$h = C_p (T_2 - T_1)$$

Where: T_1 = 27°C (80°F)
T_1 = Flue Gas Temperature
Cp = Specific Heat
h = Enthalpy (Calculated)

An adiabatic temperature is not corrected for any heat transfer to the surroundings, making this a relative value and not in itself a description of the actual combustion process. However, the intent of Figure 2 is to show the effects of moisture evaporation on combustion temperature. The absolute value is not as important as the relative change in temperature for changes in moisture. By drawing a horizontal line through points on the curves which represent minimum air temperatures for different moisture contents, a minimum adiabatic combustion temperature can be established. The points used to establish a minimum adiabatic temperature are 50% moisture/177°C (350°F) air and 55% moisture/288°C (550°F) air, which represent good boiler operation. This minimum adiabatic temperature line intersects at 1427°C (2600°F). Operating above the line simply improves the combustion process and below the line represents poor combustion. Characteristics of poor combustion are high CO emissions, high carbon loss, and widely fluctuating furnace pressure. This 1427°C (2600°F) minimum temperature is arbitrary and in reality the minimum temperature is a band. The major point to understand is that an increase of four percentage points in fuel moisture can drop the combustion temperature 38°C (100°F). This is significant when considering, for example, bark firing with 50% moisture and 232°C (450°F) combustion air temperature. A 38°C (100°F) drop in combustion temperature shifts the combustion process into a marginal operating zone. In summarizing, the travelling grate combustion technology has been used extensively to successfully burn bark. Some important relationships and limits have been established to characterize this technology. The key points of this technology are:

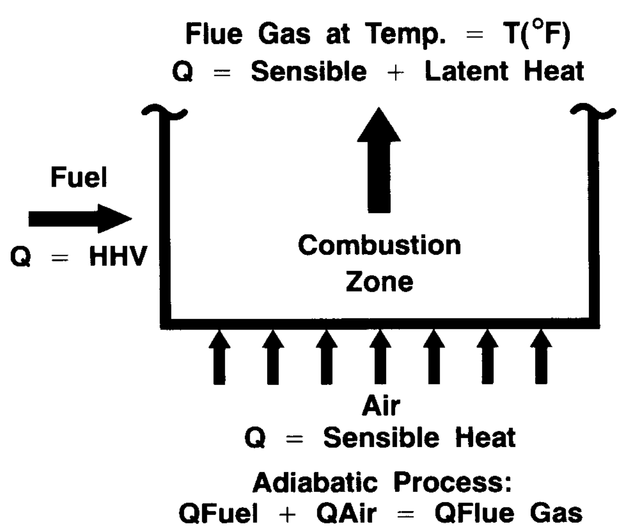

Figure 1 Simplified combustion process

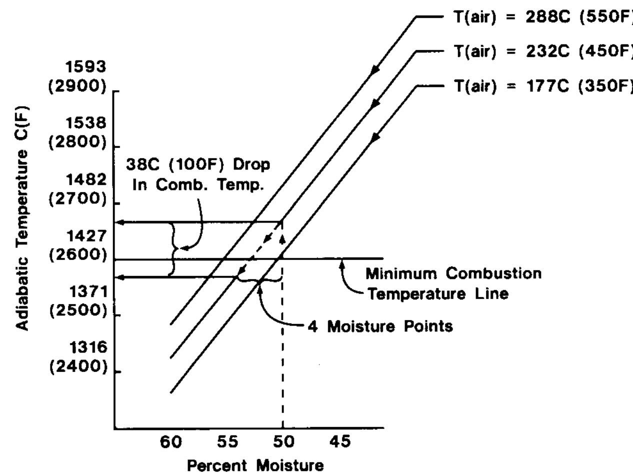

Figure 2 Evaporation effect on combustion temperature

1) Time, temperature, and turbulence drive the combustion process.

2) Given adequate time and proper fuel distribution for mixing, temperatue has the single greatest influence on the combustion process.

3) Small increases in fuel moisture content produce large decreases in the combustion zone temperature.

4) A relationship of adiabatic combustion temperature and successful operation has been established to graphically describe proper combustion.

SLUDGE CHARACTERISTICS

When considering co-firing sludge with bark, it is important to understand the differences between bark and sludge. Figure 3 lists three sludge analyses and a standard bark analysis. The sludge analyses have been normalized to 58% moisture to clearly show the differences.

The significant differences are:

1) Ash contents ranging from 20.22% to 0.2%

2) Oxygen contents from 7.91% to 21.55%

3) "As fired" Higher Heating Values (HHV) from 5043 Kj/Kg (2170 BTU/lb) to 10422 Kj/Kg (4485 BTU/lb)

Though the sludge analyses are normalized to 58% moisture, the moisture can vary between 50% and 80%. In many cases, the sludge will be higher in moisture content than the co-fired bark which increases the moisture loading in the furnace. The negative impact on combustion temperature, and consequently the combustion process, was described in the previous section. Like moisture, the high ash and low oxygen content in sludge further reduces the combustion zone temperature.

High Ash

Ash absorbs heat during combustion and reaches an equilibrium temperature in the combustion zone. The combustion zone temperature is related to the enthalpy of the flue gas:

$$h = C_p \times T_{Combustion\ Zone}$$

Enthalpy is the total heat available* divided by the flue gas weight. The ash that is carried by the flue gas becomes a the part of the flue gas weight.

As the quantity of ash increases, the flue gas weight is increasing while the total heat available remains constant. Therefore, enthalpy of the flue gas decreases:

$$h = \frac{heat}{mass} = \frac{\text{total heat available}}{\text{flue gas weight}}$$

From the first equation, a decrease in enthalpy results in a decrease in the combustion zone temperature (C_p remains relatively constant). Note the total heat available is remaining constant because the heat in the ash is transferred to the pressure parts in the convection pass. There is slight inefficiency caused by the ash leaving the convection pass which increases the total heat available, but the impact is very small compared to the impact on the combustion zone temperature.

Low Oxygen

Listed for each fuel in Figure 3 is the theoretical air requirement. This theoretical air is the amount of air required to release 10550 Kj (10,000 Btu). Sludge requires more air than bark to release the same amount of heat due to the lower oxygen content in the sludge. This extra air tempers the combustion temperature by diluting the resultant flue gas with extra cooler air, which results in lower combustion zone temperatures.

% By Weight	1 Deinking Sludge	2 Deinking Sludge	3 Pulp Mill Sludge	4 Bark
Moisture	58.00	58.00	58.00	50.00
Carbon	12.10	13.07	21.66	25.15
Hydrogen	1.48	1.83	2.40	3.10
Nitrogen	0.22	0.36	0.40	--
Sulfur	0.07	0.08	0.39	--
Ash	20.22	14.00	4.86	.20
Oxygen	7.91	12.66	12.29	21.55
	100.0	100.0	100.0	100.0
HHV Wet (BTU/lb)	2170	2208	3885	4485
HHV Dry (BTU/lb)	5167	5257	9250	8970
Theoretical Air (lb/10KB)	7.217	7.217	7.234	6.77
HHV Wet (KJ/Kg)	5043	5131	9028	10422
HHV Dry (KJ/Kg)	12007	12216	21495	20844
Theoretical Air (Kg/KJ)	3.11	3.11	3.12	2.92

Figure 3 Sludge and bark analyses

To compensate for the effects of higher ash loadings and lower fuel bound oxygen contents, the moisture must be lowered to produce the same combustion zone temperature as bark-only. This is shown graphically in Figure 4. A curve representing sludge-only has been added to the adiabatic combustion temperature versus fuel moisture content graph. Following the 1427°C (2600°F) minimum temperature line from left to right, the sludge must be five moisture points drier to produce the same combustion temperature as bark-only. These five moisture points represent the effects of the higher ash and lower fuel bound oxygen contents in terms of equivalent moisture.

Heat Available: Heat which is available to make steam. Does not include latent heat of evaporation since this heat is not available unless there is a condensor in the flue gas stream and the heat goes to steam production in the boiler.

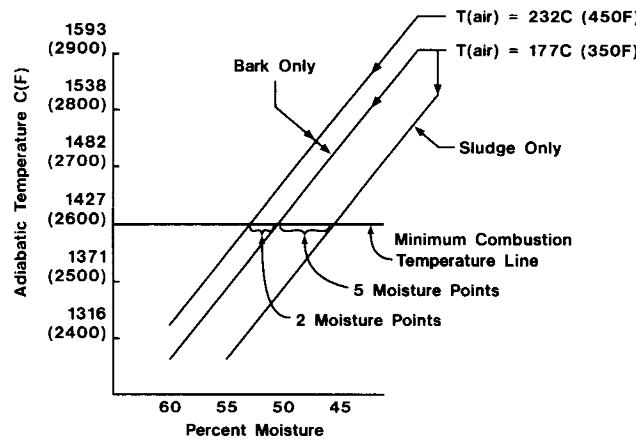

Figure 4 Lower moisture compensation for higher ash, lower fuel-bound oxygen

CO-FIRING SLUDGE WITH BARK ON A TRAVELLING GRATE

The ability of a given boiler to burn some amount of sludge depends on where the current operation falls on Figure 4. If the current bark-only firing operation is above the minimum combustion temperature limit, there is some margin in the design to co-fire sludge with bark. To estimate the amount of margin, relationships can be developed from Figure 4 to help in the evaluation. Following the minimum combustion temperature limit line from left to right, the bark-only 177°C (350°F) air line intersects at 50% moisture. Continuing on, the sludge-only 177°C (350°F) air line intersects at 45% moisture. Remember, this offset in the bark to sludge curves is caused by ash and oxygen effects only. For sludge to burn like bark the equivalent of five moisture points must be compensated in some way. Therefore, changing from all bark to all sludge is worth five equivalent moisture points. It then follows that:

90% Bark/10% Sludge = .5 Moisture Point
80% Bark/20% Sludge = 1.0 Moisture Point

One way of compensating for equivalent moisture points is hotter combustion air which adds heat to the combustion process and helps evaporate moisture (or equally compensates for equivalent moisture points). The intersections of bark-only 177°C (350°F) and 232°C (450°F) lines with the minimum temperature line compensates for about two moisture points. Therefore, 38°C (100°F) increments in air temperature are worth two moisture points, or one moisture point is worth 10°C (50°F) in air temperature.

To tie these two relationships together consider the following example:

Assume a current operation fires bark at 50% moisture and there is a desire to co-fire sludge at 60% moisture. The amount of sludge equals 20% by weight input.

For:	36 Kg Bark (80 lb)	9.1 Kg Sludge (20 lb)	Combined Fuel
Kg of Solids (lb)	18 (40)	3.6 (8)	21.8 (48)
Kg of Moisture (lb)	18 (40)	5.5 (12)	23.6 (52)

The combined fuel moisture content is two moisture points higher than the original 50% moisture bark.

Compensation for sludge's higher ash and lower oxygen contents equals one equivalent moisture point, and compensation for the increased combined moisture content equals two moisture points, for a total compensation requirement of three moisture points. It takes 10°C (50°F) increase in air temperature to compensate for one moisture point. Therefore, the combustion air temperature must be 66°C (150°F) higher than the minimum 177°C (350°F) for the original bark-only condition. If the combustion air temperature is 260°C (500°F), then 20% input from sludge seems reasonable.

Repeating this exercise for 55% moisture bark, it would quickly become evident there is little margin in combustion air temperature to compensate for sludge addition.

When considering co-firing sludge with bark on an existing travelling grate, use the information in this paper to determine if the existing boiler is capable of handling the quantity of sludge. If it is close, simply try to fire the sludge under controlled conditions and make a determination. If the results are unsatisfactory, there are additional equipment evaluations to consider:

- Raise the combustion air temperature by removing economizer surface and adding airheater surface. Air temperatures over 260°C (500°F) would require considering ductile iron grates.
- The original overfire air system may be undersized in both static and capacity for higher moisture fuels. Drier fuels ignite quickly. Volatiles release in a high concentration around the fuel particle, elevate in temperature quickly, and burn on the fuel particle. For high moisture fuels, moisture evaporation suppresses the fuel particle temperature during initial devolatilization, so for a period of time, volatiles are released uncombusted. The overfire air system must not only supply oxygen to these volatiles, but impart enough kinetic energy to mix the oxygen with the volatiles, requiring the overfire air system capacity to be larger for wetter fuels. To a certain extent some of the undergrate air can be shifted to the overfire air system. With a new fan and nozzle size, quantity and location upgrade, the CO emissions and freeboard burning would be improved.
- If sludge addition is a continuous stream, covering the lower furnace walls with refractory would raise the combustion zone temperature. This option may not be desirable but may be better than the alternatives.
- New screw or belt presses sized to dewater the sludge to higher solids content could be considered.
- The sludge must be uniformly distributed over the grate; therefore, installing a mechanical mixer upstream of the fuel conveyor belt could mix the bark and sludge.

Sludge quantities up to 20% by weight can be burned on a travelling grate, but a program including an engineering analysis and perhaps testing may be required to determine the exact amount.

GRATE TECHNOLOGY IMPROVEMENTS

The grate firing combustion technology has evolved to meet the need to fire higher moisture bark and, most recently, co-firing sludge with bark. Figure 5 shows a boiler equipped with an inclined water-cooled vibrating grate and overfire air arches in the furnace. This combustion technology can be retrofitted to an existing power boiler or offered for new installations.

Water-cooled grates permit higher combustion air temperatures without the higher maintenance associated with operating travelling grates at elevated combustion air temperatures. As described previously, the hotter combustion air adds heat to the combustion process. This additional heat either increases the combustion temperature for improved combustion or evaporates additional moisture in the fuel at the same combustion temperature.

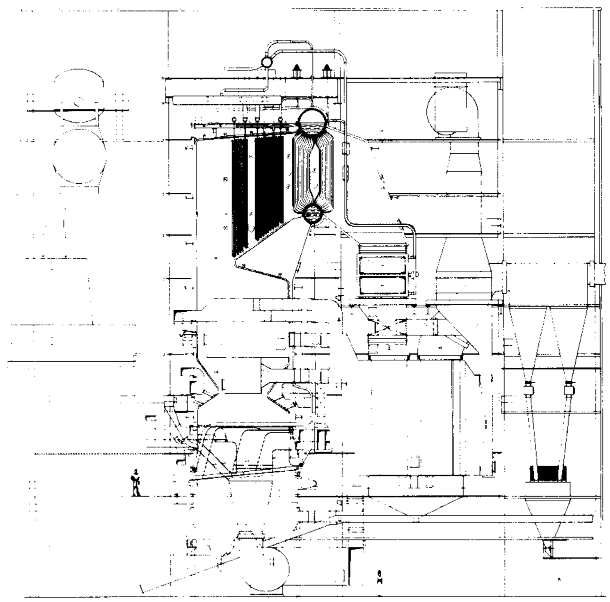

Figure 5 Inclined water-cooled vibrating grate and overfire air arches

In any overfire air system, penetration and coverage are important. The opposing arch design improves both of these by reducing the penetration distance and the plan area to be covered.

The combined improvements of a water-cooled grate, larger overfire air system, and opposing arches increase the maximum bark moisture content to 55%. Sludge addition is still a function of equivalent moisture points and total combined moisture, but 343°C (650°F) combustion air temperature allows for approximately 10% more sludge input over the travelling grate.

ATMOSPHERIC FLUID BED COMBUSTION

Burning bark and some quantity of sludge on a grate has moisture content limits due to moisture evaporation and its effect on combustion temperature. However, there are situations where the combined solid fuel moisture content will exceed these limits. Adding sludge to an already too wet bark, or wanting to burn 100% sludge in a dedicated boiler, are examples. Since additional moisture would lower the combustion temperature beyond the point of successful operation on a grate, the combustion technology must be changed to allow successful burning at significantly lower combustion temperatures. The application of Atmospheric Fluid Bed Combustion provides this ability.

Bubbling Bed

Before describing the combustion process, a physical description of a bubbling bed would be helpful.

A bubbling bed furnace has a flat bottom with a windbox attached from below. The flat furnace bottom has bubble caps attached on a .1m x .1m (4in. x 4in.) pattern. A bubble cap is a vertical pipe with a 16-hole distributor cap attached to the top. Air from the windbox flows through the bubble caps and, because there are so many caps, the air is uniformly distributed.

The furnace bottom is filled with an inert bed material, such as sand or limestone, to a depth of .6m to 1.2m (2 to 4 feet). When air flows through the bed, the inert material expands to a height of .9m to 1.5m (3 to 5 feet). The bed material has a certain particle size distribution. When the air flows through the bed material, kinetic energy is imparted to the particles. The fine particles are carried out of the bed with the air stream and the very coarse particles sink to the bottom. The intermediate size particles are lifted, but because these particles are too large (heavy) to be carried away they either fall back into the bed after the kinetic energy decays or the particles remain in the bed after transferring their kinetic energy to other particles during collisions. The bed particles are buoyant and the fuel added to the bed exhibits all the properties of buoyancy.

The physical appearance of a fluid bed can be compared to a pot of boiling water. When water boils steam bubbles cause a turbulent water flow pattern. Light particles (e.g.: rice) would be caught up in the flow patterns and circulate around the pot (buoyancy). Large particles (e.g.: eggs) would simply sit on the bottom of the pot and upset the natural flow pattern of the water. In a fluid bed, the "water" is an inert bed material and the "steam bubbles" are the air bubbles; the appearance as well as physical properties of the bed material are fluid.

During operation the bubbling bed typically operates between 760°C (1400°F) and 904°C (1600°F). When a solid fuel particle is dropped into this hot fluid mass, the moisture evaporates and the fuel ignites quickly, even though this process takes place at significantly lower temperatures. The reason for this is the high heat transfer due to conduction. An example is a pot of boiling water on a stove. Placing a hand in the steam coming directly off the top for a short period of time will not burn the hand. However, placing a hand in the boiler water will severely burn the hand. Both the steam and the water are at 100°C (212°F) yet the boiling water causes the skin temperature to increase rapidly. The reason is the high heat transfer associated with conduction. For a more analytical explanation of the bubbling bed heat transfer, consider the following:

The heat transfer in a stoker-fired furnace is primarily by radiation. For example:

$Q_{Rad} = \epsilon\sigma A \ (T_2^4 - T_1^4)$

Where:
- ϵ = Emissivity = 0.4
- σ = Stefan-Boltzmann constant = 0.1714×10^{-8} Btu/hr-ft^2-°R^4 = 5.669×10^{-8} W/m^2-°K^4
- A = Area
- T_2 = Combustion Temperature (°R)
- T_1 = Fuel Temperature (°R)

Assume: T_2 = 1427°C (2600°F) & T_1 = 27°C (80°F)

Then Q/A = Heat Transfer Per Unit Area

$= 0.4 \times 0.1714 \times 10^{-8} (3060^4 - 540^4)$

$= 60053$ Btu/hr-ft^2

The heat transfer in a bubbling bed is characterized by the conduction formulate. For example:

$Q_{Cond.} = U A (T_2 - T_1)$

Where:
- U = Overall Conductance
- A = Area
- T_2 = Bed Temperature
- T_1 = Fuel Temperature

Assume: T_2 = 904°C (1600°F) & T_1 = 27°C (80°F)

U = 45 Btu/hr-ft^2 - °F = 225 W/m^2 - °C

Then: Q/A = 45 (1600 - 80) = 68,400 Btu/hr-ft^2

The heat transferred to the fuel particle is nearly the same for these two types of combustion technologies. However, if the combustion temperature for the grate technology decreased as little as 38°C (100°F), the resultant heat transfer to the fuel particle would drop to 52,572 Btu/hr-ft^2. The heat transferred to the fuel particle in a bubbling bed remains high as long as the bed temperature is maintained.

To explain how bed temperature is controlled, refer to the simplified combustion process in Figure 6. Fuel's chemical heat and air's sensible heat combine to produce a flue gas. In this example, the exiting flue gas is at 904°C (1600°F), and to force this result, heat is either added to or removed from the bed. Consider the following:

$$Q_{in} = Q_{out}$$

Fuel Heat + Air Heat = Flue Gas Heat at 904°C (1600°F) = ± Q

Fuel Heat + Air Heat - Flue Gas Heat at 904°C (1600°F) = ± Q

±Q represents the amount of heat that must be added to or removed from the bed to control 904°C (1600°F) bed temperature.

For some fuels, such as bark or coal, the chemical heat released by the fuel is in excess of the amount of heat given up by the bed material to ignite the fuel. Therefore, Q is positive and pressure part surface is required in the bed to remove this excess heat. Otherwise, the bed temperature would increase far above the desired 904°C (1600°F).

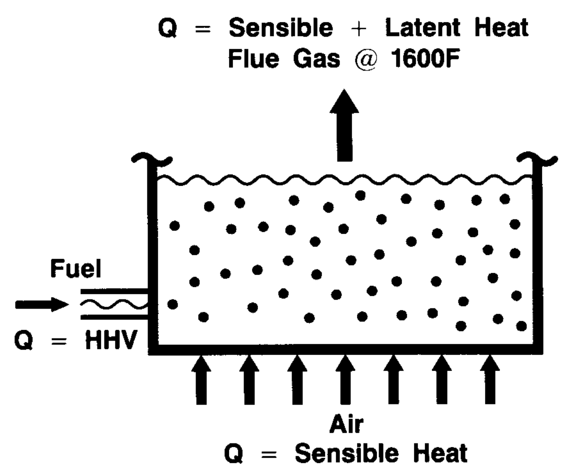

Figure 6 Simplified combustion process — bed temperature control

For other fuels, such as sewage sludge, where dewatering is typically low and moisture contents exceed 65%, the bed material must give up more heat to evaporate the moisture than is given back to the bed by the fuel's chemical heat. Therefore, Q is negative and another source of heat must be added to the bed. Typically, bark, coal, oil or natural gas are co-fired in the bed. Otherwise, the bed temperature would fall below the desired 760°C (1400°F).

For some fuels, such as pulp sludge, the amount of heat given up by the bed material to evaporate moisture and to heat the fuel particle to ignition equals the heat given up by the fuel. This typically occurs between 58% and 62% moisture depending on the HHV and ash content of the sludge. This means 904°C (1600°F) flue gas leaves the bed for steam production with all of the simplicity of a bubbling bed without in-bed surface. When considering a bubbling bed to burn predominantly sludge, the basis should be to dewater the sludge to the point where no in-bed surface is required. This occurs at bark/ sludge combinations or sludge-only moisture contents of approximately 58% to 62%.

Circulating Fluid Bed Technology

When it is necessary to burn sludge with high quantities of bark, coal or some other relatively higher Btu solid fuel, a circulating fluid bed avoids the use of in-bed surface.

Referring back to the bubbling bed discussion, burning bark or coal produces an excess amount of heat (Q) in the bed. To remove this excess heat, in-bed surface would be required, which can be undesirable. Another method of removing this excess heat would be to remove some amount of hot material out of the bed, cool this material down, then put it back into the bed. This cooled material is a heat sink for the hotter material in the bed. Once there is equilibrium between hot material leaving and cooler material entering the bed, the desired bed temperature will be controlled.

One way of transferring hot bed material out of the bed is by circulating the bed to the furnace enclosure which is the basis of the Circulating Fluid Bed (CFB). In a simplified explanation of the CFB process, heat is removed from the combustion zone by blowing bed material into the furnace. The hot bed material comes in contact with the furnace walls, gives up some of its heat, and reduces its temperature. The cooled particles return to the combustion zone by simply falling down the walls or through hot particulate collection devices. As the amount of material flowing in and out of the combustion zone and to and from the furnace walls increases, the temperatures of the bed material and the material throughout the furnace become practically equal.

Bubbling Bed Gasifier

Typically, bubbling beds operate with excess air in the bed. However, another method of controlling bed temperature is operating the bubbling bed as a gasifier. By supplying only a portion of the required combustion air to the bed (reducing atmosphere), only a portion of the fuel's chemical heat can be released in the bed. The remaining fuel leaves the bed in the forms of CO, methane and other gaseous hydrocarbons. Using a well-designed overfire air system, the remaining heat is released in the furnace.

This type of bed temperature control relies on controlling the amount of heat released in the bed versus the heat released in the furnace (combustion split). As the fuel's HHV increases (as from sludge to bark to coal) the amount of heat released to the furnace must increase to control the bed temperature within the desired limits. For bark, this combustion split is approximately 50/50. That is, half of the fuel's chemical heat is released in the bed which evaporates most of the fuel's moisture and produces a 904°C (1600°F) flue gas. The remaining heat is released in the furnace, which raises furnace flue gas temperatures to approximately 2000°F. For coal, this combustion split would have to be in the order of 30/70. That is, only 30% of the heat can be released in the bed because there is far less moisture to evaporate resulting in much more heat available to increase temperature. With 70% heat release in the furnace, temperatures in the furnace would exceed 1093°C (2500°F) which increases NO_x and SO_x emissions—defeating the intent of a fluid bed. This method of bed temperature control works for fuels in the 6971 Kj/Kg (3000 Btu/lb) to 10457 Kj/Kg (4500 Btu/lb) range and higher Btu fuels are better suited for circulating fluid beds.

Another consideration for this method of bed temperature control is the amount and chemistry of the ash. Alkalis in the ash combine with alumina and silica to form eutectics which can have low melting points. These eutectics coat the bed material and remain in the bed. If the conditions are such that the eutectics melt or become sticky, agglomerates will form and left uncontrolled would lead to defluidization and shutdown of the boiler. Operating in a reducing atmosphere can significantly lower these eutectic melting temperatures, which can accelerate this process.

Methods of controlling alkali build-up in the bed include limiting the amount of alkali fed to the bed or draining a portion of the bed material and increasing the fresh bed material make-up (much like steam drum blowdown for controlling boiler water chemistry).

EMISSIONS

In an earlier section, sludge analyses were used to show differences between bark and sludge. The high moisture, high ash and low oxygen contents were later shown to be the key elements in making sludge difficult to burn. How these key elements impact combustion technologies have been described purely on the basis of combusting the fuel successfully. However, burning sludge has an environmental impact and a further characterization of the sludge analyses is needed.

Figure 7 lists the elements contributing to the major pollutants using the analyses from Figure 3. The elements are normalized on a gm/MJ (lb/10^6 Btu) basis for a direct comparison of one fuel to another.

		Deinking Sludge	Pulp Sludge	Bark
N_2	gm/MJ (lb/MKB)	.737 (1.63)	.466 (1.03)	.403 (.89) (N_2 = 0.4%)
S	gm/MJ (lb/MKB)	.163 (0.36)	.452 (1.00)	– – –
Ash	gm/MJ (lb/MKB)	28.7 (63.4)	5.7 (12.51)	.204 (.45)

Figure 7 Elements contributing to major pollutants

When sludge is displacing bark in an existing bark-fired boiler, nitrogen, sulfur and ash all increase. The higher nitrogen content in the deinking sludge leads to proportionately larger increases in the NO_x emissions. Deinking sludge releases sulfur, but due to its high ash content which is rich in calcium, this sludge is not expected to release all of the sulfur as SO_2. Pulp mill sludge is a major contributor of sulfur and due to the relatively low ash content, most of this sulfur is expected to release. The ash contents of both sludges are significantly higher than bark, and particulate emission would increase proportionately. The overall impact on the boiler emissions, of course, depends on the amount of bark displaced by sludge. However, with these order of magnitude increases, the amount of sludge combusted could easily be set by existing air permits and not necessarily the equipment's inability to burn more sludge.

CONCLUSION

At this point, there should be a good understanding of the term "Difficult to Burn". Characterizing sludge has led to greater understanding of applying the proper combustion technology making sludge no longer difficult to burn, but simply "easy to burn".

A combustion technology characterization has been developed for two of the fuels used throughout this paper. Using the deinking sludge analysis No. 2 and the 50% moisture bark from Figure 3, the chart in Figure 8 describes combustion technology choices for varying bark/sludge combinations. To the left are ranges of emissions for each technology which could drive technology decisions.

The chart is not intended to be exact, but to provide overall guidance. The technology boundaries will change for deviations in ash, moisture, HHV's and oxygen contents from those used in this characterization. Given this, some generalized statements can be made about the chart.

- Larger capacity boilers will tend to be to the left of the chart and smaller capacity boilers to the right.

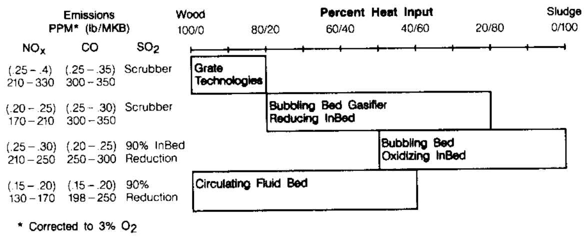

Figure 8 Combustion technology choices for varying bark/sludge combinations

- Boilers to the right of the chart will tend to be retrofits of old boilers or new stand-alone package type boilers.
- The bubbling bed boilers do not have in-bed surface.
- Coal firing capability will tend to force decisions towards CFB's.

Other technologies require SO_2 scrubbers and $DeNO_x$ to match CFB emissions.

- Alkalis in the sludge and bark ash, and in-bed SO_2 absorption could tend to shift bubbling bed combustion from reducing to oxidizing operation.
- Technically, the CFB can burn higher percentages of sludge, but some judgment was used to limit the sludge input to 60%. Designing the CFB for higher sludge inputs starts to severely compromise other fuel firing capabilities. Also, boilers firing sludge much beyond 60% input will tend to be small, simply because mills do not produce enough sludge to support much more than 45 T/hr (100,000 lb/hr) steam flow from sludge. Other technical solutions will probably be pursued for economic reasons.

In summary, sludge can be easy to burn with the right combustion technology. Knowing the right technology is very fuel specific, and having the technology characterization customized for site-specific conditions is essential to make proper combustion technology choices.