PROPERTIES AND OPERATING EXPERIENCE WITH BAGASSE AS A BOILER FUEL

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ABSTRACT

Data obtained in two investigations of bagasse as a boiler fuel are interpreted to obtain information on the properties and combustion of bagasse. Data from these investigations show that over a broad geographical region within Louisiana, bagasse has a uniform heating higher value near 8300 Btu/lb (19,300 kJ/kg), an ash content range from 4 to 18 percent, and an intrinsic ash content of about 1.5 percent. It is shown that the common sulfated ash determination overestimates the actual ash content by about 50 percent. Data on furnace draft and tramp air are used to show that the cells of pile-burning furnaces operate at about 60 percent excess air. Data is presented which shows that proper utilization of bagasse in spreader-stoker furnaces has been obtained, but both inadequate turbulence and improper fuel distribution can deteriorate their performance.

INTRODUCTION

The raw sugarcane processing industry has always depended on its own primary waste, bagasse, to provide a portion of its energy requirements. Bagasse is the fibrous and pithy material remaining after the sugar containing juice has been crushed and squeezed from the sugarcane. Raw sugar is obtained from this juice in a process involving clarification, concentration and crystallization, and each of these steps requires energy, usually in the form of low pressure steam. The whole process requires approximately 6 kg of steam/kg of raw sugar. About 4 kg of bagasse/kg of raw sugar is available for waste fuel.

Bagasse is similar in many respects both physically and chemically to other cellulosic waste fuels. The average chip size is between 2 mm and 1 cm, moisture content is usually near 50 percent (on an as-fired basis), and ash content ranges from about 4 percent to 18 percent depending on the amount of field soil which accompanies the cane. The heating value of dry, ash-free bagasse is approximately 8300 Btu/lb (19,300 kJ/kg). Proximate analysis indicates approximately 75 percent volatiles and 25 percent fixed carbon while ultimate analysis indicates 48 percent carbon, 6 percent hydrogen, and 46 percent oxygen.

Approximately a third of the initial mass of sugarcane becomes bagasse, so there is a very large waste stream to contend with during grinding. The practice of burning bagasse in boiler furnaces has been viewed in the past partially as a simple incineration of this waste while energy recovery has been secondary. With current energy prices, assured future escalation and potentially limited supply, optimum bagasse energy utilization is a high priority goal for this industry.

Research and development work directed toward the optimum utilization of bagasse goes back many years. Some of the very early work was performed by Kerr [1,2], former superintendent of the Audubon Sugar Institute (ASI) at Louisiana State University. The primary work of this institute has been to investigate technical problems
associated with cane sugar processing and refining. Recently a program of work on bagasse utilization was initiated at ASI. Two field and laboratory studies have resulted in theses on bagasse quality by Aquirre [3] and bagasse boiler operation by Kwok [4]. The purpose of this paper is to examine and interpret some of these recent data, particularly that due to Kwok, to establish some bagasse furnace operating characteristics.

Both cell type and stoker type furnaces are currently used for burning bagasse. The characteristics of these two methods of firing are quite different, so a discussion of the physical phenomena occurring in each will be presented along with the interpretation of operating data. Emphasis will be given to cell burning because it is so widely used for bagasse while stokers have been more commonly used for other waste and fossil fuels.

The discussion has been broken into three parts. The first part deals with bagasse characteristics. Observed heating value and ash content of bagasse will be presented, along with a discussion of the potential effect of ash on combustion rate. This will be followed by a section dealing with cell burning of bagasse. This section will include discussion of the physical phenomena occurring on the bagasse pile, the quantity and effect of tramp air in the furnace and, the amount of combustible gas carryover. The final section will deal with stoker firing of bagasse and will examine some aspects of field operating problems.

**BAGASSE MOISTURE, ASH CONTENT, AND HEATING VALUE**

There are many characteristics and properties of waste fuels which affect their suitability and ease of use as a boiler fuel. Moisture, ash content, and heating value are the three most important characteristics, and these were the properties examined by both Aquirre [3, 5] and Kwok [4]. Aquirre's work dealt primarily with ash and soil content of bagasse and the influence of soil type and rain pattern on the bagasse ash content. He used the very common sugar industry sulfated ash procedure. This procedure involves the saturation of a dried sample with H₂SO₄ and heating until carbonized, then firing the sample until the carbon is burned, resaturating and firing until a constant weight is obtained, the percent of sulfated ash being thus obtained. He determined that the intrinsic ash in samples of bagasse derived from Louisiana sugar cane is between 1 percent and 2 percent while the as-fired ash content of bagasse generally ranged from 4 percent to 18 percent, although higher values have been observed [7]. Bagasse ash increased dramatically with rainfall except where very effective cane washing facilities were employed. This increase in ash with rainfall indicated that the cut cane in the field picked up or was splattered with mud during harvesting.

In the factory studies by Kwok [4] the moisture content, ash content and heating value of a large number of samples of as-fired bagasse were taken from three widely separated factories. Figure 1 is a plot of all of the bomb calorimeter heating value data plotted as a function of sulfated ash content. It is, of course, not possible to obtain a sample of ash-free bagasse, but an extrapolation back to zero ash does give an approximation. The limited scatter of the data from these three different factories indicates that the intercept at 8300 Btu/lb (19,300 kJ/kg) is a reliable value for bagasse higher heating value dry on an ash-free basis and is consistent with other work [8].

![FIG. 1. THE EFFECTS OF ASH CONTENT ON BAGASSE HEATING VALUE. THE SOLID LINE IS AN LMS FIT OF THE DATA. DASHED LINE INDICATES THE ANTICIPATED SLOPE OF DATA WITH ACTUAL ASH CONTENT.](image-url)

The solid line through the data points in Fig. 1 is a least mean square fit with a slope of ~52.5 Btu/lb/percent sulfated ash (~0.122 MJ/kg/percent sulfated ash). From the combustion point of view, ash is the material which has no heating value. As such, "ash" should reduce the observed heating value on a direct combustible mass replacement basis so that the anticipated slope would be ~83 Btu/lb/percent actual ash (~0.183 MJ/kg/percent actual ash), as indicated by the dashed line in Fig. 1. It can be concluded that although the sulfated
ash technique appears to give reliable and consistent results, it overestimates the noncombustible fraction of as-fired bagasse. The actual ash content is 63 percent of the measured sulfated ash content indicating an overestimation of approximately 50 percent.

The effect of ash content on combustion rate has not been examined with field tests, but it is a common observation that unburned carbon in the residue and supplemental fossil fuel firing increase sharply with increased ash content. The relatively small volume and mass of ash accompanying the combustible matter in bagasse would make it seem unlikely that ash could coat the bagasse particles and retard mass and heat transfer to a substantial degree. What may be the primary factor is that “ash” acts as a sponge for water. The work of both Aquirre [3] and Kwok [4] indicates that the measured moisture content of the bagasse did not vary substantially at a given factory and what variation did occur was unrelated to ash (or trash) content. The ash does replace combustible matter as part of the dry component of bagasse so that for a given moisture level the mass of water to mass of combustible matter increases rapidly with ash content, as shown in Fig. 2. A fairly acceptable moisture content of 50 percent coupled with 18 percent ash (the highest observed value) yields a water to combustible ratio equivalent to 61 percent moisture, ash-free bagasse and a correspondingly very low as-fired heating value (approx. 4500 Btu/lb).

This view of the effect of ash on the combustibility of bagasse does indicate one reason for the observed effects of high ash. Recent data [9] indicates there may also be a direct gas phase chemical effect on the bagasse volatile combustion rate.

CELL BURNING OF BAGASSE

A typical pile burning bagasse boiler consists of a modestly rated boiler section on top or just to the side of a furnace which is divided into two sections. The top section of the furnace is open, is usually refractory lined rather than waterwall, and contains openings for supplemental fuel firing and feedchutes for dropping bagasse into the cells in the lower section. The lower section is broken into cells which are typically 7 ft (2 m) in average diameter, round or oblong, and approximately 7 ft (2 m) high. Most installations employ two or four cells although three cell arrangements have been used.

The cells are refractory lined with refractory floors. Air is introduced through tuyeres in the cell walls generally at two levels; within 8 in. (20 cm) of the floor, and near the top of the cell. Relatively low pressure forced draft air is used with plenum pressures of approximately 2 in. wg (500 Pa). The bagasse pile is conical with a 60 deg. slope. The base of the pile extends to the perimeter of the cell when fully charged.

Burning of the bagasse occurs in three overlapping zones; the drying zone near the top of the pile, the volatilization zone near the mid-level of the pile and the char burnout zone around the base of the pile. Traditionally, most of the forced draft air has been directed at the char burning zone. Energy is radiated from the luminous char to the surrounding refractory and a portion of this is reradiated to the pile to promote drying and volatilization. Refractory arrangement is obviously important, although little design effort has been directed towards this aspect of bagasse burning. The volatiles mix with air and burn in the cell above the pile or in the upper section of the furnace. Radiation from the burning volatiles, or the hot combustion products, could contribute to the energy radiated to the drying and volatilization zones. However, lack of a large luminous flame probably indicates limited radiation from this source.

It is difficult to measure the excess air level at which a cell operates. The feedchutes in the upper section of the furnace are generally open so that
large amounts of tramp air are drawn into the furnace by the furnace draft. This air enters at low velocity and so is unlikely to mix with the flow up from the cells. This air serves no useful purpose and does substantially increase dry gas losses and reduce boiler efficiency. Excess air levels over 300 percent have been observed, although a range between 100 and 150 percent is more common.

This tramp air should be a function of the furnace draft so that an estimate of the cell excess air can be obtained from the data taken by Kwok [4]. Figure 3 is a plot of observed excess air versus furnace draft. The solid line in this figure is a least mean square fit on the data to an expression which assumes the tramp air is a function of the square root of the furnace draft. The intercept at 65 percent excess air, although subject to some uncertainty due to the data, does correlate well with other observations [10] of excess air taken at near zero tramp air flow (indicated by the flow of furnace gas out of the feedchutes).

Kwok observed and reported the level of combustible gas in the flue stream. This data in conjunction with the excess air and heating value data can be used to calculate the percent of bagasse energy lost in the flue gas combustible, \( F_c \). Because no simultaneous particulate sampling and analysis was performed, this figure, \( F_c \), does not account for the fraction of energy lost as solid combustible, which may range from 1 to 5 percent.

The cell type boiler examined by Kwok showed a consistent \( F_c \) of 2.02 ± 0.32 percent with variations which show no relationship to either firing rate or observed excess air. This probably indicates that the relationship of physical processes which occur in pile burning do not change through a normal load range and that little mixing of the tramp air with the combustion product stream occurs within the cell.

**STOKER FIRING OF BAGASSE**

Bagasse is fired in spreader-stoker furnaces in a manner similar to other waste and fossil fuels. The usual problems associated with feeding this waste material, distributing it evenly on the grates, and proportioning the air between undergrate and over fire occur with bagasse as with the other fuels. However, proper operation can be achieved. This is indicated by Kwok's data for two identical spreader stokers at one factory. Excess air for these units ranges from 25 to 100 percent but for the most part remained within the range of 40 to 70 percent. Figure 4 is a plot of the percent of energy lost in the flue gas combustible, \( F_c \), for data from both boilers. The solid line in these plots are eye-ball brackets of the observed data. The parabolic shape is typical for spreader-stoker firing. The pronounced low excess air wing indicates a lack of available oxygen for combustion under mixing conditions which can be achieved in these large units.

A third spreader-stoker boiler was tested by Kwok and also showed no relationship between excess air (typically near 50 percent) and firing rate, but did show a strong relationship between
combustible loss and firing rate (as indicated by the variation in the fraction of steam flow rating for the boiler) as shown in Fig. 5. The sharp decrease in combustible loss with increased firing rate probably indicates that turbulence levels are insufficient to insure good mixing and that combustion is not complete at lower firing rates even though ample retention time is available. Increased overfire jet velocity is indicated.

A fourth boiler tested by Kwok yielded both exceptionally high excess air levels and a strong relationship between the three quantities, of excess air, firing rate and combustible loss. This is shown in Fig. 6. As in the previous boiler, combustible loss is very high and here efficiency loss due to excess air would also be very high. Furnace draft for this boiler is well controlled and relatively low so that tramp air is probably not a primary problem. The rapid decrease in excess air and combustible loss with increased firing probably indicates that improper feeding and distribution has resulted in bare grate areas and primary air channelling. Higher firing rates would tend to more fully cover the grate and improve the boiler operation. Better fuel distribution would improve this situation for all firing rates.

CONCLUSIONS

Work at the Audubon Sugar Institute at Louisiana State University on bagasse quality and bagasse boiler operation has resulted in a data base for field operation of boilers in the raw sugar-cane processing industry. The data has been used to show that:

1. Dry ash-free bagasse in Louisiana has a relatively uniform higher heating value of 8300 Btu/lb (19,300 kJ/kg), on a moisture and ash free basis.
2. The total ash content of as-fired bagasse is between 4 and 18 percent while the intrinsic ash (that associated with the cane) is between 1 and 2 percent.
3. The sulfated ash determination commonly used by the sugar industry overestimates the quantity of zero-heating-value material in bagasse by about 50 percent. The actual ash content is 63 percent of the observed sulfated ash content.
4. Tramp air entering through open feedchutes is a source of high excess air in cell furnaces.
5. The cells in cell type bagasse furnaces operate with an excess air of approximately 60 to 65 percent, excluding tramp air.
6. Effective utilization of bagasse in spreader-stoker furnaces has been obtained in some instances. However, both inadequate turbulence levels and improper fuel distribution can markedly deteriorate the performance of these units.
REFERENCES


Key Words
Boiler
Bulky Wastes
Burning
Combustible
Energy
Fiber
Furnace