Energy Management Study in Sugar Industries by Various Bagasse Drying Methods

Geethanjali S. Yarnal[2], Vinod S. Puranik[2]

ABSTRACT

In this article, bagasse drying methods based on flue gas and steam drying in the sugar industry are analyzed, and new methods are proposed for maximum removal of moisture to save energy. Wet bagasse, usually having 50 percent moisture in the Indian sugar cane industry, has been taken as a case for improving calorific value. Methods like flue gas drying and steam drying are analyzed. A new technique, namely, combined flue gas and steam drying, is developed in this article and the excess amount of energy required in drying up the wet baggage using the steam drying is calculated. The combined flue gas/steam drying technique is compared with parallel and sequential heating techniques for the moisture removed, boiler efficiency, increase in calorific value, etc. The experiments were conducted to find the performance on a small scale, and they were used to estimate for the whole plant, using extrapolation. It is proven that combined flue gas/steam drying is far superior to the rest of the techniques.

Keywords: bagasse drying, boiler efficiency, flue gas drying, steam drying, combined flue gas/steam drying.

INTRODUCTION

Thermal energy is basically available in the sugar industry in the form of the chemical energy of fossil fuels and bagasse. The bagasse is

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a byproduct of sugar crane crushing, and fossil fuels are bought from the market. Both of these fuels can be used to generate high pressure and high temperature steam for the purpose of manufacturing sugar and for generating electric power, which can be used internally as well as supplied to the grid. Hence, care should be taken to extract as much thermal energy from the fuels as possible, since it contributes to higher revenues. Also, use of extra fuels must be avoided by increasing the efficiency of heat extraction from the fuels to avoid the detrimental effect that these fuels cause to the environment. Increasing the efficiency of heat extraction from the fossil fuels is beyond the scope of this research work, as the chemical content of the fossil fuels cannot be altered inside a sugar industry. But it is always possible to modify the percentage composition of the bagasse by treating it with proper techniques. Hence, this research work focuses more on increasing the percentage composition of constituent elements of the bagasse.

The sugar industry produces, by cogeneration, electric energy for its own use and for sale. Bagasse, a fibrous material that is one of the main byproducts of a cane sugar manufacturing plant, is obtained after the sugar juice is leached out of sugarcane. Bagasse is further used in the production of additional energy like electrical energy [1-4]. Currently, the need for the energy required in the form of heat supplied to the boilers in the sugar industry is met partially from the bagasse and partially from fossil fuel reserves like oil and natural gas. Bagasse has a moisture content of around 50-52 percent as it leaves the milling process. Bagasse drying is a matter of keen interest to the sugar industry, due to its utilization as fuel in boilers. The improvement of the use of bagasse in the furnaces is currently an important industrial strategy. This subject has become of great interest due to the increasing level of cogeneration in recent years. There is more focus on thermal analysis of the systems rather than total energy efficiency [5-10]. One such effort is to increase the calorific value of the bagasse.

Bone dried bagasse presents a gross calorific value of 17632 kJ/kg. Because of the moisture, the net calorific value at 50 percent moisture is only about 8816 kJ/kg [11,12]. In addition to increasing the gross calorific value, the reduction of moisture content in the bagasse also reduces the volume of the flue gases. Furthermore, the specific heat of water vapor is almost twice that of the other gases; hence, the reduction of water vapor in the combustion gases will result in a higher combustion temperature, thus improving boiler efficiency. Bagasse drying is a concept which deserves additional attention and development efforts. Since the ultimate aim is to achieve energy economy in the combustion of bagasse, it is necessary that the energy balance be always kept in mind while various concepts are developed. This shows drying bagasse before firing in the boilers could save a considerable amount of fuel.

Removing moisture from wet objects is a complicated process, which is described as reduction of product moisture to the required dryness values. All units that enable the product to reach the drying values (by heating and dehumidification) are described as the drying system. In order to maximize profits, it is necessary to minimize the wastage that can occur during drying. It is the intent of this research to extract as much heat as possible from bagasse, thereby reducing usage of the fossil fuels. Basically, the calorific value of the bagasse can be increased by heating the bagasse with moisture content. By extracting the heat supplied, the temperature of the moisture increases and finally vaporizes after reaching the boiling temperature. The boiling temperature of pure water at ambient temperature is 100°C. Hence, one may need to heat the wet bagasse to a temperature above the boiling point. There are three different ways that the moisture in the wet bagasse can be removed; they are explained in the following sections.

Downing *et al*. [13] investigated the potential of mechanical dewatering of bagasse and came to the conclusion that it is limited to approximately 40 percent moisture. Roll crushers rarely perform to the limit, and an average of 43 percent moisture content would be considered excellent performance. A further moisture reduction of bagasse can be achieved by the thermal drying methods discussed. Nebra and Macedo [14] published information on a dryer which was used for bagasse drying in a sugar industry. This dryer was designed and built according to a project developed by the Centro de Tecnologia Copersucar in Brazil. It was a flash drier that could work with 25 ton bagasse/h, the biggest flash dryer reported until now. Arrascaeta *et al*. [15] designed a bagasse dryer that elutriates the bagasse, separating the particles into different sizes. The design has used both fluidized and pneumatic conceptions. Salermo and Santana [16] designed and manufactured a dryer which worked with up to 10 t/h of 47 percent moisture content in wet bagasse. Final moisture content in their design was reduced to 35 percent in wet bagasse, and the inlet gas temperature that they used was 250ºC. Cárdenas *et al*. [17] described a pneumatic dryer on a large scale. They studied both the energetic and exergetic efficiencies of a coupled boiler-dryer system. Augustinsky [18] explained the installation of two pneumatic dryers at Brazilian sugar industries in 1984 and in 2004. Meirelles explained [19] drying of the wet bagasse in a fluidized bed dryer. He observed that, due to bagasse cohesive characteristics, a mixer was necessary to allow fluidization. Some researchers have been working with drying of agricultural residues like sugar cane bagasse in cyclone. A review of drying in cyclone by a group from the School of Mechanical Engineering and the School of Chemical Engineering from the State University of Campinas is presented by Nebra *et al*.[20]. Juan et. al.[21] have reviewed the sugar cane bagasse drying techniques in detail. The review is comprehensive, and they have presented the complete chronology of the equipment and principles used in drying the sugar cane bagasse. They focused mainly on the development of rotary and pneumatic driers.

Flue gas drying has been used for decades in the cane sugar industry [22]. Using flue gas heating, It is possible to increase the boiler efficiency by approximately 3 to 5 percent and to generate additional steam by this measure. Modern boiler waste heat recovery systems [23] have been applied in the industry as well, in order to optimize the boiler efficiency to the same extent.

Steam drying is not a brand new technology in the industry. It has been being used in the beet sugar industry for beet cossette drying since 1982 in pilot plants [24] and since 1990 on a technical scale [25], and it has also been applied to dry wood chips, coal, meat products, and sewage sludge.

ORGANIZATION OF THE ARTICLE

Section 3 deals with the theoretical analysis of the bagasse drying methods. Results that are compared among the heating techniques are presented in section 4. Finally, Section 5 concludes the present research work.

BAGASSE DRYING METHODS

Bagasse Drying with Internal Heating

A popular method is steam drying, in which mixing of the bagasse moisture with high temperature steam takes place. (The steam at high temperature comes in contact with the moisture of the bagasse, and the heat is exchanged between the steam and the moisture.) The moisture also becomes vapor by extracting the heat from the steam, and they mix with each other. The total steam available in the system is removed by means of an external pump or by venting. As a result, the steam that is supplied will be subject to a temperature drop, thereby increasing the temperature of the moisture. Since the heat is extracted from the steam, it cannot be used at some other stage in the process where high temperature is required. Figure 1 shows the schematic diagram of the experimental setup of bagasse drying with internal heating. It mainly consists of a boiler that produces steam at high pressure and temperature. The steam thus generated can be used partly in the sugar manufacturing process and partly for drying up the bagasse. The steam is allowed to enter the vessel that has the wet bagasse lying in it. Once the steam at high temperature comes into contact with the moisture, the heat exchange takes place, and the moisture also vaporizes. The temperature of the steam coming from the boiler drops, thereby increasing the temperature of the water vapor after they are mixed with each other. Care should be taken that the final temperature of the mix is above the boiling temperature of water, preferably around 120°C. The temperature at which the steam should be supplied to the vessel is calculated as follows.

Let

γ = % loss due to conduction heating of solid mass of the bagasse and the steel vessel.

Total enthalpy of the steam can be calculated as follows.

$$Q_{Tot.Int.Heat} = Q_{Th.Heat}[1 + \gamma]$$

$$= 390{,}392 \text{ kJ} \left[1 + \frac{30}{100}\right]$$

$$= 507{,}513.5 \text{ kJ}$$

If the method of external heating is used, more heat energy may be needed than the heat required in the method of internal heating. This may be attributed to the heat loss due to radiation and convection.

The steel vessel can be designed to reduce the loss of heat energy due to natural convention by coating it internally with refractory material. The inlet temperature of high temperature steam to the dryer can be calculated as below.

$$Q_{Tot.Int.Heat} = \lambda \times C_p \times [T_{Final} - T_{initial}] \text{in kJ}$$

where λ = mass of the steam to be supplied by the boiler in kg
= 1000 kg

$$T_{initial} = T_{final} - \left[\frac{Q_{Tot.Int.Heat}}{\lambda \times C_{p-Steam}}\right]$$

$$= (120°C) - \left[\frac{(507{,}513.7 \text{ kJ})}{(1000 \text{ kg}) \times (2.007 \text{ kj/kg°C})}\right]$$

$$= 373°C$$

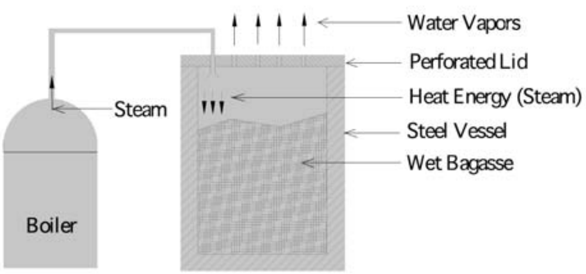

Figure 1. Experimental Setup of Bagasse Drying with Internal Heating

Considering the heat required only to heat the moisture so that its final temperature becomes 120°C, without considering the heat loss to surroundings, the initial temperature of the steam coming from the boiler is calculated as follows.

$$= (120°C) - \left[\frac{(390{,}392 \text{ kJ})}{(1000 \text{ kg}) \times (4.186 \text{ kj/kg°C})}\right]$$

$$= 213°C$$

The minus for $Q_{Tot.Int.Heat}$ indicates the heat loss from the steam. But one may not be able to tap the exact temperature of steam at 213°C in the process or be able to produce the steam at such high temperatures. For this reason, one can vary the mass of the steam supplied so that the initial temperature of the steam is available in the process. But one condition which should always be maintained is that the final temperature of the steam should never go below 120°C, since it may become condensed. Also, another flexibility of choosing the initial temperature is based on the Pinch Technology temperature profiles, and the corresponding mass can be calculated.

An assumption made in these calculations is that there is a heat loss of 30 percent in heating the solid mass of the bagasse and the surroundings. However, these values change, based on the size of the vessel, mass of bagasse, and its specific heat.

Bagasse Drying with Hot Flue Gases

In this setup, the heat content of the flue gases that comes out of the boiler is extracted and used for heating the bagasse. The drier that holds the bagasse is installed in line with the boiler stack gases. Since the boiler stack gases contain enormous amount of energy, their exit temperature from the boiler is usually around 250°C. This method of heating can be employed in tandem with the other heating techniques, since it uses the energy of the waste gases which would otherwise go into the environment, thereby increasing its entropy. Usually, the boiler is heated with an excel air of 35 percent, and the temperature of stack gases are about 250°C. In the drier, as discussed in the method of internal heating, the inlet temperature required for the fluid entering the drier is 213°C. Hence, the flue gases can be used in place of the steam used in the method of internal heating, which can produce vapors of temperature around 120°C. Burning one kg of dry bagasse produces the heat of 17,632kJ/kg, which is the calorific value of the dry bagasse. This heat is utilized in heating the water in the boiler to produce the steam that can be used in the sugar manufacturing process. But the dry bagasse, after being burnt, leaves behind the flue gases, which escape into the atmosphere. Since the flue gases also contain much heat energy, they can be used in drying up the wet bagasse. The optimum mass of bagasse that is required to be burnt in order to remove water content from one kg of wet bagasse is calculated below.

The chemical composition of the dry bagasse (i.e. the bagasse with

0 percent of moisture content) is given below.

C (carbon)	: 51%
H (hydrogen)	: 5.6%
O (oxygen)	: 39.9%
Ash	: remaining %

The combustion products of stack gases are CO_2 and H_2O. Since the wet bagasse with 50 percent moisture is burnt with 35 percent of excess air, the composition can be found as mentioned below. The oxygen required for stoichiometric combustion of 1 kg of dry bagasse is:

$C + O_2 = CO_2$
12 kg of C + 32 kg of O_2 = 44 kg of CO_2
1 kg of C + 2.67 kg of O_2 = 3.67 kg of CO_2

Since one kg of dry bagasse contains 0.51 kg of carbon, 0.51 kg of C + 1.36 kg of O_2 = 1.87kg of CO_2, which can be interpreted as 1.36 kg of oxygen is required for the complete combustion of 0.51 kg of carbon.

Similarly, the amount of oxygen required in burning the hydrogen present in the wet bagasse is given by

$2\ H_2 + O_2 = 2H_2O$
$H_2 + 0.5\ O_2 = H_2O$
$H + 0.25\ O_2 = 0.5H_2O$
1 kg of H + 8 kg of O_2 = 9 kg of H_2O

Since one kg of dry bagasse contains 0.056 kg of H, 0.056 kg of H + 0.448 kg of O_2= 0.504 kg of H_2O, which can be interpreted as 0.448 kg of oxygen being required for the complete combustion of 0.056 kg of hydrogen.

Total oxygen required for complete combustion of one kg of wet bagasse with 51 percent of moisture is:

= 1.36 kg + 0.448 kg
= 1.808 kg

The oxygen present in one kg of dry bagasse = 0.399 kg; hence, the oxygen required from external sources is:

= 1.808 kg – 0.399 kg
= 1.408 kg

Percentage weight of oxygen in air by weight = 23.3%

$$\text{The mass of air required} = \frac{\text{mass of oxygen required}}{\text{\% weight of oxygen in air}}$$

$$= \frac{1.408 \text{ kg}}{0.233}$$

$$= 6.043 \text{ kg}$$

Theoretically, 6.043 kg of air is required for the complete combustion of one kg of dry bagasse.

The stack gas composition for complete combustion of one kg of dry bagasse is:

CO_2	: 1.87 kg
H_2O	: 0.504 kg
N_2	: 4.6394 kg

Total mass of the stack gas = mass of air supplied for complete combustion of one kg of bagasse + mass of carbon in one kg of bagasse + mass of hydrogen in one kg of bagasse + mass oxygen in one kg of bagasse

= 6.043 kg + 0.51 kg + 0.0567 kg + 0.399 kg
= 7.0087 kg

Let τ kg be the quantity of water evaporated in the dryer.

The stack gas composition for complete combustion of one kg of bagasse with 50 percent water content = composition of 0.5 kg of dry bagasse + amount of water evaporated from the wet bagasse:

CO_2: 0.5 × (1.87 kg) = 0.935 kg
N_2: 0.5 × (6.043 kg) × (1 – 0.233) = 2.3174 kg
H_2O from combustion: 0.5 × (0.504 kg) = 0.252 kg
H_2O evaporated from wet bagasse: (0.5 – τ) kg

Since 35% of excess air is supplied, mass total nitrogen

$$= (1+0.35) \times 2.3174$$
$$= 3.1285 \text{ kg}$$

mass of unused oxygen $= 0.5 \times 0.35 \times 0.233 \times 6.043$ kg
$= 0.2464$ kg

Hence, the stack gas composition for complete combustion of one kg of bagasse with 50 percent moisture content with 35 percent excess air is:

CO_2	: 0.935 kg
N_2	: 3.1285 kg
O_2	: 0.2464 kg
H_2O	: $0.252 + (0.5 - \tau)$ kg

The heat extracted from the stack gases by cooling from 250°C to 120°C…

= heat extracted from the dry components + heat extracted from the moisture evaporated from the bagasse with 50 percent water content…

= [total mass of dry components of stack gases × average specific heat of the dry components × temperature raise] + [mass of moisture evaporated from the bagasse with 50 percent water content × specific heat of water × temperature raise]

$$= [(CO_2 + N_2 + O_2) \times C_{P.DRY} \times \Delta T] + [H_2O \times C_{p.water} \times \Delta T)]$$
$$= [4.3104 \text{ kg} \times 1.015 \text{ kJ/kg °C} \times 130\text{°C}] + [(0.752 - \tau) \times 4.186 \text{ kJ/kg °C} \times 130\text{°C}]$$
$$= 568.76 \text{ kJ} + 409.22 \text{ kJ} - 544.18\ \tau$$
$$= 977.98 \text{ kJ} - 544.18\ \tau$$

The enthalpy of steam at 120°C is 2706 kJ/kg, and h_w at 27°C is 113 kJ/kg. From the heat balance, τ may be found as $\tau = 0.323$ kg, which is the water evaporated in the dryer from 1 kg of the 50 percent wet bagasse. So, the composition of the bagasse after drying is 0.5 kg of fiber and 0.177 kg of moisture. That means the mass of stack gases required to dry up one kg of wet bagasse with 50 percent water content is 7.0087 kg, leaving behind 0.177 kg of moisture in the bagasse. In order to completely remove the water content in the wet bagasse, one may need to increase the mass of the stack gases so that the extra energy supplied is utilized in removing 0.177 kg. The excess mass of dry bagasse to be burnt to produce stack gases can be calculated as below.

Total mass of stack gases produced by burning one kg of dry bagasse in the boiler = 7.0087 kg.

Amount of water content removed from one kg of wet bagasse by using stack gases produced by burning one kg of dry bagasse in the boiler = 0.323 kg.

Mass of water content remaining in the wet bagasse = 0.177 kg.

Additional mass of stack gases required to remove 0.177 kg of moisture

$$= \frac{(7{,}0087 \text{ kg}) \times (0.177 \text{ kg})}{(0.323.\text{kg})} = 3.8407 \text{ kg}$$

Additional mass of dry bagasse to be burnt in the boiler

$$= \frac{(3{,}8407 \text{ kg})}{(7.0087\text{kg})} = .55 \text{ kg}$$

Total mass of dry bagasse to be burnt in boiler to completely remove the 50 percent water content in one kg of wet bagasse = 1.00 kg + 0.55 kg = 1.55kg.

Hence, to dry up one kg of wet bagasse, one may need to burn at least 1.55kg of dry bagasse in the boiler. Since the drying up of one kg wet bagasse leaves only 0.5 kg of dry bagasse, additionally one may need 1.05 kg of dry bagasse, which does not balance the dry bagasse generated and used in this process. Hence, one may choose to compensate the excess heat content corresponding to that present in 1.05 kg of stack gases by the steam produced in the boiler, thereby creating balance between the dry bagasse used in the boiler and generated in the drier.

Figures 2 and 3 show the schematic diagram of bagasse drying methods that are popular in the sugar industry. Figure 2 depicts the parallel arrangement in which the combustion gases that leave the boiler are tapped into the preheater and drier, simultaneously in parallel. In

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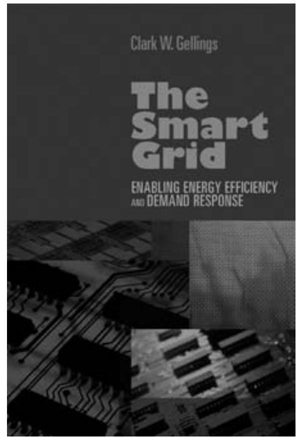

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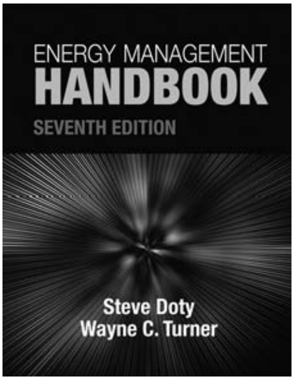

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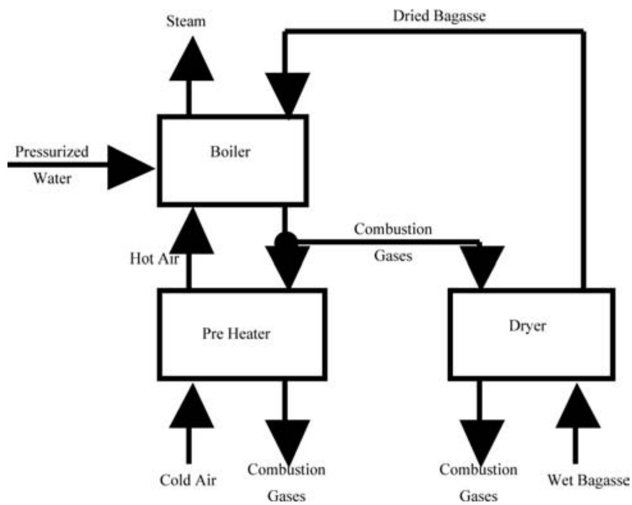

Figure 2. Parallel Flow Arrangement of Preheating and Drying

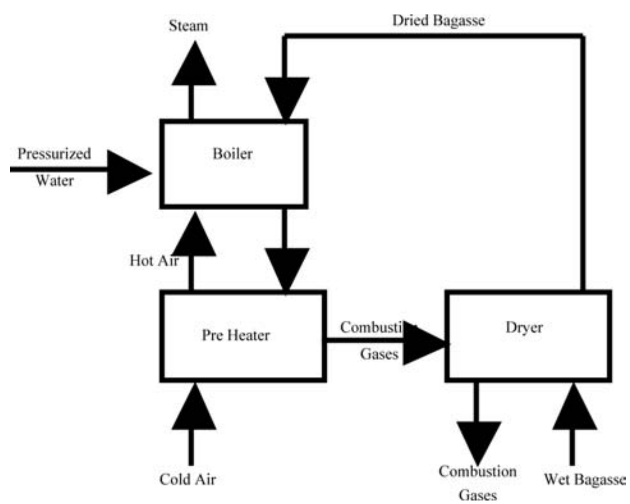

Figure 3. Sequential Flow Arrangement of Preheating and Drying

other words, the combustion gases that enter the preheater as well as the drier are at the same temperature. The preheater heats the cold air, and the drier removes the moisture from the wet bagasse.

Whereas in the case of sequential arrangement (as shown in Figure 3), the combustion gases leaving the preheater (after heating the cold air) enter the drier, the combustion gases leaving the preheater in the case of parallel flow have lots of thermal energy left in them. To increase the utilization of heat present in the combustion gases [Marquezi and Nebra (2003)], a sequential flow arrangement is designed in such a way that the combustion gases go directly from the preheater to the drier. In this case, the amount of moisture removed from the wet bagasse in the drier is less, compared to parallel flow arrangement, since the heat content of the combustion gases that enter the drier in case of sequential flow arrangement is less than that of parallel flow arrangement. In both of these methods as explained above, there is no balance between the dry bagasse used in the boiler and the dry bagasse generated in the drier. In a case where the balance is sought, then there will be moisture content of at least 17.7 percent in the bagasse.

Bagasse Drying with Combined Flue Gas/Steam Heating

A new technique is proposed in this method, based on the calculations performed in the previous section, i.e. additionally one may need heat given by burning 1.05 kg of dry bagasse in order to balance the dry bagasse used in the boiler and produced in the drier. For this purpose one may choose to compensate the excess heat content corresponding to the one that is present in 1.05 kg of stack gases with the steam produced in the boiler, thereby creating balance between the dry bagasse used in the boiler and generated in the drier. Figure 4 shows a schematic diagram of combined heating of the wet bagasse

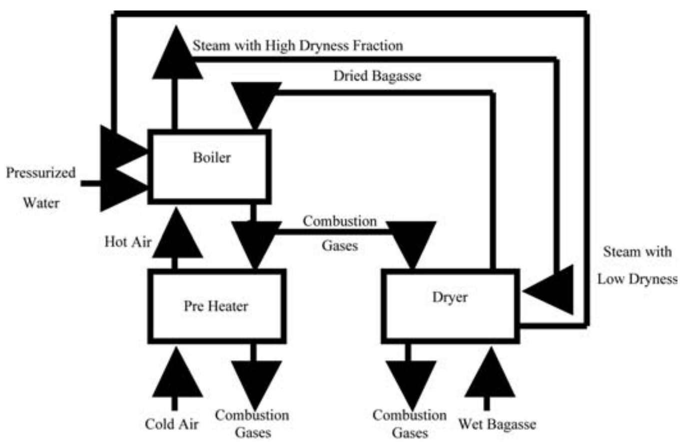

Figure 4. Schematic Diagram of Combined Heating of Wet Bagasse

in the drier using the combustion gases and steam, both coming out of the boiler.

The steam is tapped from the boiler and fed to the drier, and similarly the steam, after picking up moisture from the wet bagasse in the drier, is again fed to the boiler. In this way the enthalpy of the steam along with the vapor moisture is not lost. The excess heat that is to be supplied is calculated as follows.

Percent of moisture present in one ton of wet bagasse = 17.7%

As per the method of internal heating or steam drying, the heat required for completely removing 50 percent of moisture from one ton of wet bagasse = 390,392 kJ.

Hence, to remove 17.7 percent of moisture from the wet bagasse = 390,392 kJ × (17.7%/50%) = 138,199 kJ.

Considering the heat required only to heat the moisture so that its final temperature becomes 120°C, without considering the heat loss to surroundings, the initial temperature of 100 kg of steam coming from the boiler is calculated as follows.

$$T_{initial} = (120°C) - \left[\frac{(138,199 \text{ kJ})}{(100 \text{ kg}) \times (4.186 \text{ kJ/kg°C})}\right]$$

$$= 450°C$$

One may note that in all these calculations of heat required, the amount of heat lost in heating up the solid mass of bagasse and surroundings is not included; these two factors may be included in the calculations for more accurate results.

In this setup, there is the possibility of the combustion gases getting mixed up with the steam, and this may lead to contamination of steam with that of flue gases. In order to avoid this, these lines are operated with the EITHER/OR mode so that at any point of time there will be no mixing of the steam and combustion gases. Figures 5 and 6 show a schematic diagram of operation of the combined heating cycle with closing the path or disconnecting the lines of the steam inlet and outlet to the drier so that the combustion gases can be used initially for the drying up of wet bagasse. Once the combustion gases are evacuated, the lines of combustion gases are disconnected and the steam line is opened. By repeating this procedure, the

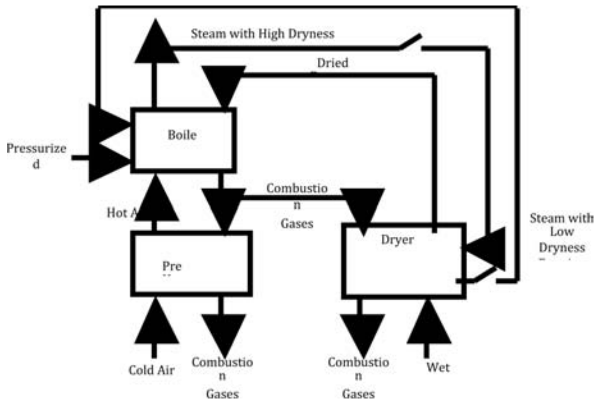

Figure 5. Schematic Diagram of Combined Heating with Steam Lines Cut Off

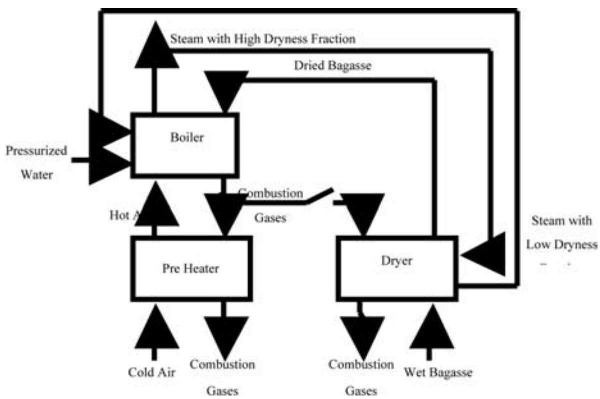

Figure 6. Schematic Diagram of Combined Heating with Lines of Combustion Gases Cut Off

drier produces one ton of dry bagasse for one ton of dry bagasse burnt in the boiler. This way the balance between the production and consumption can be achieved.

CASE STUDY

In this section, the bagasse drying methods discussed so far are verified with a case study. A medium-scale sugar industry from the Northern Karnataka region is chosen for this, and the following details pertain to the industry selected.

Cane crushing rate (tons/day)	: 12,000
Fiber content in cane	: 13.70%
Bagasse flow rate on cane	: 30%
Bagasse moisture	: 50%
Gross calorific value of bagasse at 50 % moisture	: 8816 kJ/kg
Steam demand of the sugar process:	38% on cane

Downing *et al*. [15] investigated the potential of the mechanical dewatering of bagasse and came to the conclusion that it is limited to approximately 40 percent moisture. Roll crushers rarely perform to the limit, and an average of 43 percent moisture content would be considered excellent performance. A further moisture reduction of bagasse can be achieved by the thermal drying methods discussed. Experimentations for four cases were carried out:

Case 1

Operation with a steam demand of 38 percent on cane for the sugar process using excess steam in a condensing turbine for power production.

Case 2

Operation with a steam demand of 38 percent on cane for the sugar process using excess steam in a condensing turbine for power production and using flue gas drying (parallel arrangement).

Case 3

Operation with a steam demand of 38 percent on cane for the sugar process using excess steam in a condensing turbine for power production and using flue gas drying (sequential arrangement).

Case 4

Operation with a steam demand of 38 percent on cane for the sugar process using excess steam in a condensing turbine for power production and using flue gas drying (combined arrangement).

While Case 1 is the base case, Table 1 gives an overview of the impacts of methods of bagasse drying on the boiler performance. With

Table 1. Impact of Various Drying Methods on Certain Factors in the Generation of Steam

	Units	Scenario 1	Scenario 2	Scenario 3	Scenario 4
DRYING METHOD ➔		*No drying*	*Flue gas drying-parallel arrangement*	*Flue gas drying-sequential-arrangement*	*Flue gas steam drying-combined heating arrangement*
Bagasse moisture	%	50	43	45	7.5
Heat lost from water in flue gas	%	22.8	19	21	26
Heat lost in dry flue gases	%	5.3	5.2	5.18	5.17
Unburned carbon losses	%	2.5	2.5	2.5	2.5
Radiation losses	%	0.3	0.3	0.3	0.3
Other losses	%	0.4	0.4	0.4	0.4
Gross calorific value	kJ/kg	8816	10050	9697	16310
Total steam generated	t/hr	315	359	346.5	582
Boiler efficiency	%	69	70.8	70.5	82.1

Values are projected for the operation of whole plant based on experiments conducted for processing one ton of cane.

bone dry bagasse, the boiler efficiency can be raised up to 84 percent. With parallel arrangement technique, the moisture can be removed be up to 7 percent, thereby leaving 43 percent of the moisture in the bagasse. Similarly, the sequential arrangement produces lesser quality of wet bagasse, compared to parallel arrangement, since some amount of heat is lost in this case in preheating the air going to the boiler. This method has produced a bagasse with a moisture content of 45 percent. The combined heating technique produced a bagasse with 7.5 percent moisture content. Theoretically, as per the calculations, the final moisture content in the parallel and sequential arrangements must be much less than 43 percent and 45 percent respectively. The reason for not being close to the theoretical predictions is due to the heat loss in heating up the solid mass of the bagasse and the heat loss due to conduction, convection, and radiation in and outside the drier. In the case of combined heating, the amount of steam supplied is varied until the moisture content is considerably less.

Figure 7 shows the moisture content in the bagasse after using a drying method. It clearly suggests that the flue gas/steam drying combined heating drying method is the best among the three methods listed, as it results in around 7.5 percent of moisture in the bagasse.

Similarly, Figure 8 shows how the gross calorific value changes with respect to the drying method chosen. There is not much improvement in the gross calorific value when drying takes place with parallel and sequential arrangement. However, the combined heating results in final bagasse moisture content of 7.5 percent.

As a result of increase in the gross calorific value, the total steam generated per hour also increases, which is shown is Figure 9. Combined heating method generates around 582 tons of steam per hour,

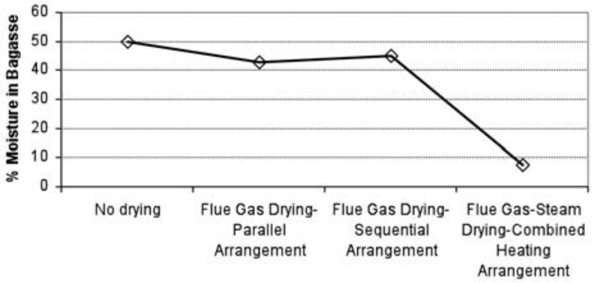

Figure 7. Percent Moisture in Bagasse vs. Drying Method

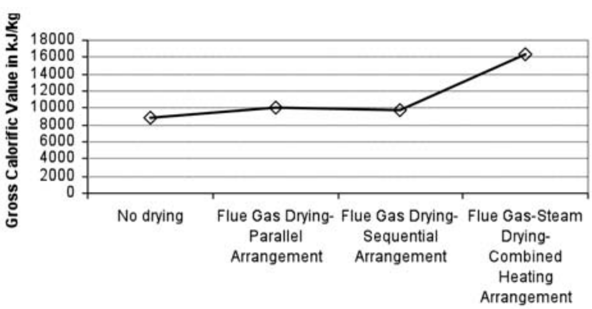

Figure 8. Gross Calorific Value after Using Drying Methods

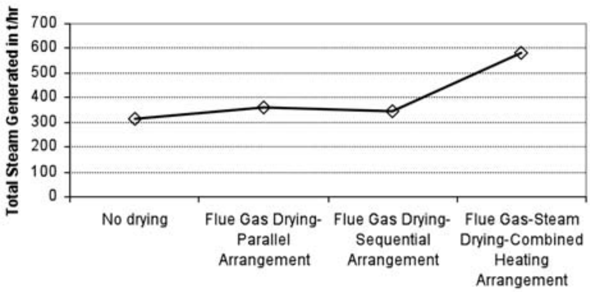

Figure 9. Total Steam Generated by Different Drying Methods

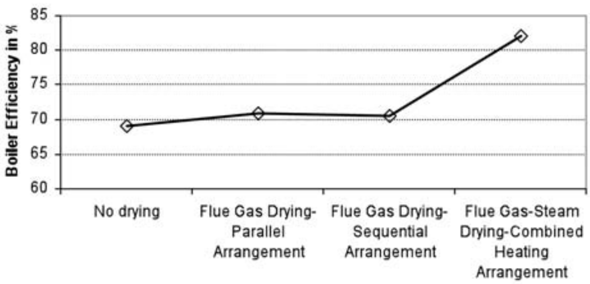

Figure 10. Total Steam Generated by Different Drying Methods

compared to 359 and 346 tons per hour by both parallel and sequential arrangement techniques, since the final moisture content using these two methods is 43 percent and 45 percent respectively.

Figure 9 shows the change in the efficiency of the boiler with respect to the heating methods. Since the combined heating with flue gas and steam results in the lowest percentage of moisture in the bagasse, it results in higher boiler efficiency compared to the other two methods. However, the energy spent in these methods is not considered, as the percentages of moisture removed (between combined heating on one hand and parallel and sequential arrangement on the other hand) have a huge difference.

CONCLUSIONS

In this article, a new technique based on combined flue gas and steam drying is developed, and the energy requirements for drying wet bagasse are calculated theoretically. Also, the experiments were conducted to show the impact of using this technique on the performance of the overall plant. The maximum amount of moisture that can be removed using the flue gas drying is calculated, and energy and steam requirements for steam drying are also calculated. In addition, the initial temperature of the steam that is to be fed from the boiler to the drier is calculated theoretically. In this method it is demonstrated that moisture can be removed by sending the flue gas and steam sequentially into the same chamber. The operation of the technique discussed has been explained pictorially.

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