Optimized Design of a Bagasse Dryer System for Sugar Industry

L. Praveen Raj and B. Stalin

Abstract--- *Bagasse is used as one of the fuels for boilers to generate power in most of the sugar industries all over the world. Bagasse consists of moisture which affects the efficiency of the boiler which in turn reduces the power output . This paper investigates about the use of pneumatic dryer system with number of steel pipes in it,within which hot steam is used as the medium for drying. Modifications in pre-existing design of the dryer such as dimension, capacity, operating temperature, working pressure and heating surface area were considered. Analytical calculations and thermal analysis has been carried out to determine the percentage reduction of moisture. Optimization has been carried out using Taguchi's technique. Parameters such as pressure, temperature and mass flow rate of the hot steam were taken into account for optimization.The work shows that 5% increase in the reduction of moisture in bagasse leads to 7% increase in boiler efficiency and 5% increase in power output.*

Keywords--- *Bagasse, Moisture Content, Pneumatic Dryer, Boiler Efficiency, Taguchi's Technique.*

I. INTRODUCTION

BAGASSE is the residual fibre that remains after the crushing of cane. It consist of water(moisture), fibre and small amount of soluble solids.Bagasse represents 12% of the total sugarcane mass. The cane, after being cut, crushed in conventional and non conventional mills in a sugar industry leaves moist bagasse. The bagasse is sometimes post-processed for other industrial applications like paper industries and bagasse is even used as a reinforcement fiber in composites . In some sugar industries around the world, the bagasse is used for power production. The investigation was carried out in "Sakthi Sugars", Padamathur, Tamilnadu, India, where a half of the total bagasse obtained is used for power production for their self-consumption. As observed, the average moisture content in the bagasse is between 50.18%-52.30%. With this percentage of the moisture content, the efficiency of the boiler is about 70.86%. The power output is about 17.5 Kw. In 1990, Professor Kerr investigated about drying bagasse. The cross section of the dryer is about 1.2 m x 1.8 m. The height of the boiler is about 6 m. He used a boiler made of steel. He observed a reduction of moisture from 54.3% to 46.4%(wet bagasse). As a result, steam production was increased. In 1991, Kinoshita designed a system consisting of four chambers. He used flue gas of the boiler for drying the bagasse.

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Three of the four installations were rotary dryers and the other, a flash dryer. In 1983, Correia designed a pneumatic transport dryer. He reported an increase in steam production of 16% by drying the bagasse from 52% to 40% moisture (w.b.). Cárdenas *et al.* (1994) described a pneumatic dryer. They studied the energetic efficiency of a boiler-dryer system. They concluded that the use of a dryer improves the boiler efficiency. This work presents the investigation and optimization of the bagasse drying system for an efficient maximization of steam generation and power production.

Table 1: Boiler Specifications

BOILER SPECIFICATIONS	
Type	Water tube boiler
Capacity	135 ton.
Working Pressure	110 bar
Temperature	540±5˚C
Boiler Exhaust	3 kg/cm² or 40 (pounds or lbs)
Heating Surface area	8709 sq. m
Steam level	60-70ton steam

Bagasse Specifications

BAGASSE SPECIFICATIONS	
Moisture	46% - 52%
Fibre (including ash)	43% - 52%
Soluble solids	2% - 6%
Average Density	150kg/m3
Low Heat Value	1780kcal/kg
High Heat Value	4,000kcal/kg

Apart from those tabulated, other properties of bagasse are: Fibre consists of cellulose-27%, Pentosans-30%, Lignin- 20%, Ash-3%, Gross Calorific Value= $4600-12S-46W$(KJ/kg), Net Calorific Value= $4250-12S-48.5W$(KJ/kg).

II. BAGASSE DRYER SYSTEM

Drying generally refers to the removal of moisture from a solid by evaporation. Based on the mode of heat transfer, the bagasse dryer system can be broadly classified into two types namely:

- Indirect dryers
- Direct dryers

The proposed system is an indirect type dryer

A. Indirect Dryers

In an Indirect type dryer, a metal wall divide the product and the heat transfer medium.The heat transfer is only through conduction and forced convection.This method can be adopted for low pressure steam bagasse which ranges about 3 atm or less. It is made by inserting large tube bundles in a large bin. Typically, the bagasse moisture can be reduced from 50% to 45%.

B. Dryer Design

In a rotary dryer, material is fed into a slowly rotating cylinder. The feedstock is lifted and cascaded down through the drying medium by the longitudinal flights inside the cylinder. Pipes with diameter ranging from 100-150 mm are placed vertically in the large bin.the pipes passes along the vertical axis. The pitch of the vertical axis ranges between 450-600 mm. The vertical steam pipes of the above mentioned dimension are lined along the circumference of the bin. The low pressure steam is fed to the individual pipes from the top. This is attained by a common feed header with radial outlets.

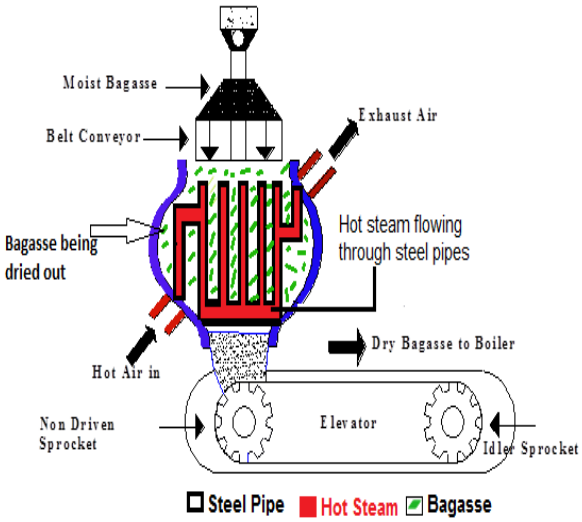

Figure 1: Bagasse Dryer System

The removal of the condensate out of the system is achieved by connecting the pipes together at the bottom end. The bagasse is made to flow from the top of the dryer. The moist bagasse travels down vertically to the bottom, where and when it makes a physical contact with the steel pipes in which hot steam is flowing. The moisture content is removed by liberating the water vapour to the top of the bin.

C. Boiler Description

This paper work has been carried out in a sugar industry. Hence the datas presented here are as observed from the industry.The reason for presenting this information about the boiler helps in understanding the calculations.

The boiler used in the industry is a drum type water tube boiler.Vertical arrangement of the steam generation tube is placed between two drums. The vertical centre line between the two drums is 9.95 m. Super heater is arranged in front of the boiler bank and is screened from the furnace by two rows of tubes. Boiler is designed for natural circulation of water and is of bottom-supported type. A balanced draught needs to be maintained inside the furnace, which is achieved by equipping the boiler with three draught fans namely, induced, forced and secondary air fans respectively. The air flow rate of the three draught fans are 3750, 1500 and 460 m^3/min respectively. The thermal efficiency of the boiler is enhanced by using economizer and air heater. Outgoing flue gases from the boiler at high temperature are utilized by such boiler accessories. The feed water pressure is maintained at 1.5 times the working pressure of the steam by a multistage centrifugal feed pump. Steam rating of the boiler is about 60 tons/hr. The designed superheated steam pressure and temperature were 23kg/cm² and 350˚C respectively. Heating surface of boiler, super heater, air heater and economizer were found to be 1565, 115 and 1015 and 135 m², respectively.

The furnace was a spreader stoker type with a volume of 254.5m^3 under the existing condition of the plant. Dumping grate area of the furnace was 251 m² comprising of eight sections. Bagasse is supplied from the main carrier to the furnace by means of four rectangular cross sectional bagasse feeders.

III. Calculations

Under the mill working conditions, the average values were taken as:

- Moisture content of bagasse (w) = 50 %
- Sucrose in bagasse (s) = 3.0 %

Based on the formulae proposed by Hu-Got in 1986, the calorific values were calculated as follows:

Gross calorific value (GCV)= 8280 (1 - W) – 2160S

Net calorific value (NCV)= 7650 - 8730 W - 2160 S

These equations for calculating GCV and NCV includes the latent heat of vaporization of water which is formed during combustion of hydrogen present in bagasse and the latent heat of vaporization of water content or the moisture content of the bagasse.

Bagasse Burnt in Terms of Standard Bagasse of 45% Moisture

$$\frac{\text{Heat value of 1kg of bagasse actually burnt}}{\text{Heat value of 1 kg of 45\% moisture bagasse}} \times \text{tonnes of bagasse}$$

Total Fuel Burnt in Terms of Standard Bagasse of 45% Moisture

Bagasse burnt into standard bagasse + All other fuel converted into standard bagasse

1 kg coal = 2.5 kg bagasse, 1kg wood = 1.25 kg bagasse, 1 lit furnace oil = 5 kg bagasse.

Equivalent Evaporation

Water evaporated from and at 100˚C:

$$\text{water evaporated} \times \frac{H - h}{539}$$

Where, H-Total heat in steam issuing from the boilers in Kcal/kg

h-Total heat in feed water in Kcal/kg

Equivalent Evaporation Percentage Cane

$$\frac{\text{Equivalent evaporation tonnes}}{\text{Tonnes of cane}} \times 100$$

Equivalent Evaporation per kg of Standard Bagasse

1. $\frac{\text{Equivalent evaporation}}{\text{Sq. m of boiler heating surface/hr}}$

2. $\frac{\text{Total equivalent evaporation in kg}}{\text{Total heating time}}$

A. Steam Obtainable per kg of Bagasse

For fuel control purposes, it is necessary to work out the quantity of steam which can theoretically be obtained from the combustion of a known weight of bagasse and that actually obtained under the working conditions of the factory. It is determined by considering the fuel value of bagasse by taking the C,H and O_2 content.

Gross Calorific Value (G.C.V)

G.C.V. = 8280 (1 - W) – 2160S Eq. (1)

= 8280 (1 - 0.50) - 2160 (0.03)

= 4075 BTU/lb

Net Calorific Value (N.C.V)

N.C.V.= 7650 - 8730 W - 2160 S Eq. (2)

= 7650 - 8730 (0.50) - 2160 (0.03)

= 3220 BTU/Lb

B. Steam Obtainable per kg of Bagasse

For fuel control purposes, it is necessary to work out the quantity of steam which can theoretically be obtained from the combustion of a known weight of bagasse and that actually obtained under he working conditions of the factory.

Steam Theoretically Obtained can be Calculated as Follows

Fuel Value of Bagasse

An average value of 4640 Kcal/kg of bone dry bagasse may be taken:

Products of Combustion

Dry bagasse: C - 46.5%

H - 6.5%

O_2 - 46%

$C + O_2 = CO_2$

12 + 32 = 44

That means, per kg of C, O_2 required will be

$$\frac{32}{12} = 2.67$$

and CO_2 will be

$$\frac{44}{12} = 3.67$$

Per kg of H, O_2 required to form water will be $H_2 + O = H_2O$

2.016 + 16 = 18.016 (or) per kg of H, O_2 required will be

$$\frac{16}{2.016} = 7.93 \text{ kg}$$

H_2O formed will be 8.93 kg. Hence 1 kg of dry bagasse of the above composition will then require:

(0.465 X 2.67) + (0.65 X 7.93) = 1.75 kg of O_2

As bagasse has 0.46 O_2 already, 1.75 - 0.46 = 1.29 kg of O_2

As oxygen in air is 23% by weight, 1.29 kg of O_2 will come from 5.6 kg of air and the producs of combustion from 1 kg of dry bagasse will be:

1. Due to CO: (0.465 X 3.67) = 1.70 kg of CO2
2. Due to H : (0.65 X 8.93) = 0.58 kg of H2O

If air has 1% moisture, 0.56 kg air will contain 0.56 kg H_2O. Hence total H_2O will be 0.58+0.56 = 0.636 kg.

Nitrogen introduced with air will be 5.6 X 0.76 = 4.256 kg (N_2) being 76% by weight of air., An excess air has to be used for enuring proper combustion. The various products of combustion with excess air of about 50 % ,75% , 100% will be as follows:

With Excess Air, Quantity of H2O, N2, O2 will Increase

With 50% excess air quantity is 5.6 + 2.8 = 8.4 kg

Moisture = 0.084

Total H_2O will bee 0.58 + 0.84 = 0.664

If bagasse has 45% moisture, then 55% dry matter has:

1. C will be -0.465 X 0.55 = 0.256
2. H_2 will be - 0.65 X 0.55 = 0.357
3. O_2 will be – 0.46 X 0.55 = 0.253

Now C to form CO_2 will require 0.256 X 7.93 O_2

H to form water will require 0.357 X 7.93 = 0.283 O_2

Total oxygen required will be0.683 + 0.283 = 0.966 kg

0.253O_2 is already present in air hence 0.966 - 0.253 = 0.713 which gives:

$$\frac{0.713 \times 100}{23} = 3.1 \text{ kg of air}$$

C. Theoritcal Quantity of Steam Obtainable from Bagasse Having 45% Moisture

- On basis of air at 27˚C and fuel gas temperature at 260˚C the steam available (from at 100˚C) can be worked out as follows:
- It is accepted that each kg of water % in the flue gas whether due to associated water or combined water about 694 k.cal of heat and each kg of gas whether CO_2 or nitrogen or O_2 about 55.56 k.cal of heat.
- Then heat loss due to associated water will be 0.45 X 694 = 312 k.cal and that due to combined water 0.32 X 694 = 222 k.cal.

1. With 50% excess air heat loss in gases will be:

CO_2 = 0.94

N = 3.53

= 0.36

Total = 4.83 X 55.56 = 268 k.cal.

Total heat loss in water and gases will be:

312+222+268 = =802 k.cal.

2. With 75% of excess air heat losses in gases will be:

CO_2 = 0.94

N = 4.122

O = 0.534

Total = 5.596

Heat loss will be 5.596 X 55.56 = 311 k.cal. and toal loss in flue gas will be

312+222+311 = 845k.cal.

3. Similarly with 100 % excess air, heat losses in gases will be:

CO_2 = 0.94

N = 4.712

O = 0.713

Total = 6.365 X 55.56 = 354 k.cal.

Total heat loss = 312+222+354 = 888 k.cal.

Now fuel value of bone dry bagasse may be taken as 4640 k.cal. that for 45% of moist bagasse or 55% 0f dry matter will be 4640 X 0.55 = 2552 k.cal.

Then heat available for steam production in above cases viz. 50%, 75%, 100% excess air will be:

50% excess air = 2532 – 802 = 1750 k.cal.

75% excess air = 2532 – 845 = 1707 k.cal.

100% excess air = 2532 – 888 = 1664 k.cal.

Now latent heat of steam being 539k.cal., steam obtainable per kg of bagasse will be respectively:

$$\frac{1750}{530} = 8.25 \text{ kg}$$

$$\frac{1707}{539} = 3.17 \text{ kg}$$

$$\frac{1664}{539} = 3.68 \text{ kg}$$

D. Boiler Efficiency

The efficiency of the boiler was founded out by the following equation:

q = ð (1 - w) (1.4 m - 0.13) + 0.5 ð (t - 32)

Boiler Efficiency on the Basis of Flue Gases Temperature

At the stack section of the boiler, the flue gas temperature leaving from the boiler ranged between 310 °F and 330 °F. Hence the average flue gsa value was considered as 320 °F. The values were recorded from the totalizer. Some heat losses from the furnace in the boiler were considered to determine the quantity of the steam that could be obtained from unit weight of bagasse. They are as follows:

a. Latent heat of water(moisture) due to combustion of hydrogen in bagasse.
b. Latent heat of vaporization of water(moisture) in bagasse.
c. Sensible heat lost from the flue gases leaving out of the boiler at stack section.
d. Losses due to non-combusted solids.
e. Radiation losses from furnace.
f. Losses due to incomplete combustion of carbon giving CO (carbon mono oxide) instead of CO2 (carbon dioxide).

Out of the six losses mentioned above, latent heat of water and latent heat of vaporization of water have already been considered in Eq.(1) & Eq.(2) for determining calorific value of bagasse. A considerable loss (c), which remains to be accounted for is the sensible heat lost in the flue gases, which is given by the following equation:

q = ð (1 - w) (1.4 m - 0.13) + 0.5 ð (t - 32) Eq. (3)

Where

q = Sensible heat lost in the flue gases in BTU/lb of bagasse.

t = Temperature of flue gases at the stack. Its value is taken as 320˚F

w = Weight of moisture per unit weight of bagasse.

m= Ratio of weight of actual air required for combustion to weight theoretically necessary. Its value depends on the type of furnace used. For spreader stroker furnace, the excess air required is 50 % of the theoretical air required. Its value is taken as 1.50.

Substituting these values in Eq. (3)

q = (1 - 0.50) (1.4 x 1.50 - 0.13) + 0.5 (320 - 32)

q = (0.50 x 1.97+ 0.5) (288)

q = 1.485 x 288

q = 428 BTU/lb.

The other three losses such as (d) Losses due to non-combusted solids, (e) Radiation losses from furnace, (f) Losses due to incomplete combustion of carbon giving CO (carbon mono oxide) instead of CO2 (carbon dioxide), were also considered and so the calculation is as follows:

The quantity of remaining heat transferred to steam is given by the expression:

Mv = (7650 - 2160 s - 8730 w- q) Eq. (4)

Where

ð = Co-efficient representing heat loss due to unburnt solids. For spreader stroker furnaces, its normal value is taken as 0.975.

Þ = Co-efficient to account for heat losses by radiation. This value varies from 0.95 to 0.99 for more or less efficient lagging. Its value is taken as 0.97.

ñ = Co-efficient of incomplete combustion. Its value is taken as 0.95.

Mv = Heat transferred to steam per pound of bagasse in BTU/lb.

Substituting the values of w, s, q ,ñ,ð&Þ

Mv = ñ (7650 - 2160 x 0.03 - 8730 x 0.50) - 428) ð x0.975 x 0.97 x 0.95

Mv = (7650 - 64.80 - 4365 - 428) x 0.898

Mv = 2792 x 0.898

Mv = 2507 BTU/lb

Boiler efficiency = Mv / N.C.V

Boiler efficiency = 2507/3220

Boiler efficiency = 77.86 %

III. RESULTS AND DISCUSSIONS

The results of the calculated values have been compared on the basis of steam obtainable per Kg of bagasse with 50% moisture and steam obtainable per Kg of bagasse with 45% moisture. The comparisons were tabulated separately to understand the effect of drying the moisture content in the bagasse. Steam obtainable per Kg of bagasse with 50% moisture with Increased quantities of N_2 and O_2 at 50%, 75% and 100% excess air as follows:

Obtainable Steam Per Kg of Bagasse (50%)

Products	Excess air			
	None	50%	75%	100%
CO_2	1.700	1.700	1.700	1.700
H_2O	0.636	0.664	0.678	0.692
N_2	4.256	6.384	7.448	8.512
O_2		0.644	0.966	1.288

Steam obtainable per Kg of bagasse with 45% moisture with Increased quantities of N_2 and O_2 at 50%,75% and 100% excess air as follows:

Obtainable Steam Per Kg of Bagasse (45%)

Products	Excess air			
	None	50%	75%	100%
CO_2	0.940	0.940	0.940	0.940
H_2O	0.800	0.816	0.824	0.832
NO_2	2.360	3.534	4.122	4.712
O_2		0.356	0.534	0.713

TABLE III and TABLE IV shows that moisture reduced bagasse yields higher amount of steam.

A. *Taguchi Analysis*

The Taguchi analysis is carried out by considering the data collected from the industry, literature and depending upon the analytical data available.

Taguchi Analysis

	Temperature(°C)			Pressure(MPa)			Mass Flow Rate(Kg/s)		
Flow	I	II	III	I	II	III	I	II	III
1	38	38	38	1	1	1	26.8	24.6	24.6
2	77	77	77	1	3	2	18.6	18.6	18.6
3	32	32	32	1	2	3	97	77	77
4	258	297	152	1	1	1	97	77	77
5	500	500	500	74	67	74	62.6	62.3	62.3
6	401	401	401	71	71	73	62.6	62.6	62.3
7	262	218	305	65	65	65	7.08	6.84	6.84
8	168	79	219	65	65	65	121.9	99.8	99.8
9	175	198	170	66	66	66	121.9	99.8	99.8

Based on the values obtained using the Taguchi analysis the system is optimized at 500°C, pressure values ranging from 67MPa-74MPa with a mass flow rate 62.3Kg/s.

B. *Result of Thermal Analysis of Dryer by ANSYS*

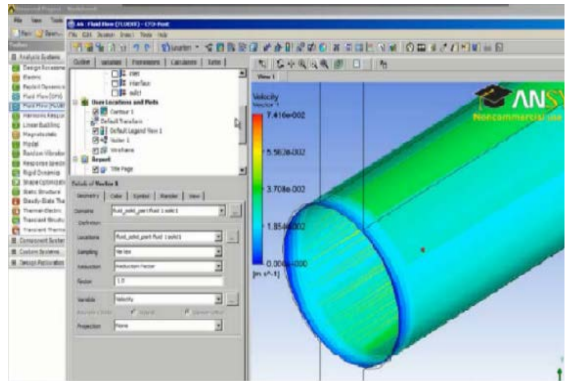

Figure 2: Analysis Report 1

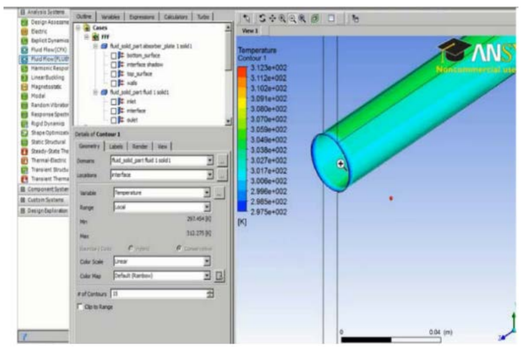

Figure 3: Analysis Report 2

IV. CONCLUSION

Hence the investigation work shows that the proposed design of the bagasse dryer plays a major role in increasing the boiler efficiency that leads to increased power output.. The calculation shows that there is an increase in boiler efficiency about 77.86% (about 7% increase)with the designed dryer and power output has increased up to 5%. It is suggested that further developments in design of dryer will give still better performance of boiler**.**

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