Design of Bagasse Dryer to Recover Energy of Water Tube Boiler in a Sugar Factory

Sankalp Shrivastav[1], Ibrahim Hussain[2]

[1]M. E Student (Mechanical) in Thermal and Design,
Institute of Engineering and Technology, Devi Ahilya Vishaw Vidhayalay, Indore, India

[2]Assistant Professor, Mechanical Department, Institute of Engineering and Technology
Devi Ahilya Vishaw Vidhayalay, Indore, India

Abstract: ***Drying bagasse by using flue gas which comes from air preheater to chimney is an optimum solution to enhance efficiency of boiler in sugar factory as bagasse has high calorific value but due to its moisture about 50% not able to use its full heat. The present work suggest to place Cylindrical shell type dryer, in between the air preheater and chimney, and flue gas pass from dryer's one end and from another end bagasse by carriage, makes dryer to act as a counter flow heat exchanger where flue gas gives its heat at 190°C to the bagasse at 45°C this reduce moisture of bagasse from 50% to 46%, increased CV of bagasse around 784 KJ/kg which increases boiler efficiency from 79% to 81% in sugar industries.***

Keywords: bagasse, boiler efficiency, Dryer,moisture contain

1. Introduction

Bagasse is a by-product/waste of sugarcane in the sugar industry. Bagasse is a fuel of varying composition and heating value. These characteristics depend on the climate, type of soil upon which the cane is grown, variety of cane, harvesting method, amount of cane washing, and the efficiency of the milling plant. In general, bagasse has a heating value between 1,600and 2,200 kcal/kg (3,000 and 4,000 Btu/lb.) on a wet, as-fired basis. Most bagasse has moisture content between 45 and 55 per cent by weight. The lower bagasse moisture contents are generally found in Hawaii. Typically a mill wet bagasse contains 50% moisture with a gross calorific value of 2270 kcal/kg (˜1900 KJ/kg).[1] Normally bagasse is directly fed to the boiler to generate the steam and surplus bagasse is stored in bagasse yard. It is a well-known fact that calorific value of bagasse is decrease with increase in moisture of bagasse. The GCV of bagasse can be determined by the following equation: GCV [1] = 196.05 x(100-W_w % -W_A %)-31.14xW_{RDs} KJ/kg Where :W_w – is the moister content, W_A – is the ash content W_{RDs} -is the BRIX .Study shows that 1% reduction of moisture in bagasse increased its calorific value of 196 KJ/kg (47 Kcal/kg).And 1% reduction of moisture in bagasse increases 0.5% boiler's efficiency if its use as a fuel in boiler.[2] Hence if bagasse drying by flue gas through dryer will enhance efficiency of boiler.

2. The data collected from bankedi sugar mill are for a boiler using coal as the fuel. Find out the boiler efficiency by indirect method [3]

Fuel firing= 5599.17 kg/hr, Steam generation rate= 21937.5 kg/hr, Steam pressure= 43 kg/cm2 Generated Steam temperature =377°C ,Feed water temperature= 96° C %CO2 in Flue= 14 %CO in flue gas = 0.55 ,Average flue gas temperature= 190° C ,Ambient temperature = 31°C , Humidity in ambient air= 0.0204 kg / kg dry air ,Surface temperature of boiler= 70°C, Wind velocity around the boiler =3.5 m/s

2.1Fuel Analysis (in %)

Ash content in fuel=8.63, Moisture in coal=31.6, Carbon content=41.65, Hydrogen content=2.0413, Nitrogen content=1.6, Oxygen content=14.48, GCV of Coal =3501 kCal/kg

2.2Boiler efficiency by indirect method

Summary of Heat Balance for Coal Fired Boiler

3. Ultimate Analysis of Bagasse and Coal [6]

Bagasse (%) Carbon=22.16, Hydrogen=2.84, Oxygen= 21.0, Nitrogen=0, Sulphur=0, Ash=4, Moisture=50 **coal (%)** Carbon=67.20, Hydrogen=4, Oxygen=6, Nitrogen=1.8, Sulphur=1, Ash=12, Moisture=8

4. Design of Bagasse Dryer

At a temperature of t °C the kinematic viscosity of air is approximated by:

ν= (0.1335 + 0.925×10^{-3} t)$10^{-4}$$m^2$/s eq. (1) giving a value at 200°C of 0.000032 m^2/s.The Reynolds number for a flue gas velocity of 9 m/s in a dryer of 750 mm diameter is those= 9 x 0.75 / 32 x10^{-6} = 210900 which is well into the turbulent regime. The emissivity of the flue gas is low; hence the predominant mode of heat transfer is forced convection.

A relationship for forced convection from a turbulent gas flow inside a cylindrical tube is: Nu = 0.023 $Re^{0.8}$ $Pr^{0.4}$eq.(2) Where the Nussle number, Nu, is given by:

Nu=$h_i d_i$/k, and the prandtl number, Pr, by

$P_r = c_p\mu/k$, Most gases have a value of Pr of about 0.74, and this value is substantially independent of temperature, hence equation (2) simplifies to:

$N_u = 0.02\ Re^{0.8}$ and the coefficient of heat transfer is obtained knowing the diameter of the tube, d, and the thermal conductivity of the gas, k. The thermal conductivity of air can be obtained from:

$k_{air}= 0.02442 + 0.6992\times10^{-4}$ t [7] W/m/K where t is the temperature in °C. At 200°C this gives a value of 0.0384 W/m/K.

The Nusselt number, Nu, is Nu=0.02× $(210900)^{0.8}$=363, the coefficient of heat transfer: $h_i= N_u$ x k / d_i = 363 x 0.0384/0.75 h_i= 18.6 W/m^2/K,A dryer exposed to the wind approximates to a cylinder with its axis at right-angles to the direction of the flow. The relevant heat transfer relationship, valid for Reynolds numbers between 10^3 and $10^5$is:Nu=0.26 $Re^{0.6}Pr^{0.3}$, Assuming a constant value for Prandtl number for air of 0.74, this expression simplifies to:

$$Nu = 0.24\,Re^{0.6}$$

In this case the Reynolds and Nusselt numbers refer to the outside diameter, d_o, of the dryer. The outside convective heat transfer coefficient is then given by:$h_{c,o}= N_u k/d_o$,At 25°C the kinematic viscosity of air ν= (0.1335+0.925×10-3×25)10-4 [6] = 0.0000156m2/s, The Reynolds number is:Re = 10 x 0.75 / 15.6 x10-6 =5.43 x 105

Nu=0.024(5.43×105)0.6 (from eq. 2)=662.4,The thermal conductivity of air at 25°Cis:k= 0.02442+ (0.6992×10-4×25) = 0.0248 W/m/K,giving an outside convective film coefficient $h_{c,o}$= (662.4 x 0.0248) / 0.75,$h_{c,o}$ = 21.9 W/m2/K However, in circumstances such as these a linear approximation can be made to the radioactive heat transfer component and an outside film coefficient defined in terms of the convective and radioactive components thus $h_o= h_{c,o}+ \varepsilon h_{r,o}$,Where ε is the emissivity of the surface and $h_{r,o}$ is a linearized radiation surface heat transfer coefficient, which is dependent on the surface temperature of the dryer and the temperature of the surroundings. For typical situations a reasonable value for $h_{r,o}$ is 5 W/m^2/K. The emissivity will depend on the outside finish of the dryer steel metal finish (ε=0.07), we have: h_o= 21.96 + 0.07 × 5= 22.31 W/m^2/K. The internal and external heat transfer coefficients have been estimated as 18.6 and 22.31 W/m^2/K respectively. Calculate the overall U-value. Neglecting the thermal resistance of the two metal layers: U_o = 1 / [1/20 + 0.05 / 0.04 + 1/23] = 0.746 W/m^2/K.

4.1 Bagasse after Drying

C_p of bagasse=0 .46KJ/kg K [8]Q= $C_c[T_{bo}- T_{bi}]$ $T_{bo=}$ temperature of bagasse at outlet of dryer ,T_{bi} = temperature of bagasse at inlet of dryer

$T_{bo}=Q/C_c+T_{bi}$ But Q= € C_{min} $[T_{gi}- T_{bi}]$,C_c= mass flow rate of bagasse x heat capacity of bagasse C_c= 7 kg/s X .46 KJ/kg K = 14.36 kJ/s K ,C_h= mass flow rate of flue gases x heat capacity of flue gas ,C_h=7.562 x .23 =1.73 kJ/s K ,$C_h=C_{min}$=1.73 kJ/s K ,NTU= UA/ C_{min} NTU=.746x3.14x12x.75/1.73 = 12.18 ,€= 1-exp [-NTU [1-Cr]] / 1- Cr exp [-NTU [1-Cr]] ,Where Cr= C_{min}/C_{max} = 1.73/14.36 = 0.12 ,€= 1.12 Thus Q= € C_{min} [T_{gi}- T_{bi}] ,Q= 1.12 x 1.73 [473-308] =319.7 W,So $T_{bo}=Q/C_c+T_{bi}$

4.2 Final Temperature of Bagasse After Drying

T_{bo} =[319.7/14.36]+ 308
T_{bo} = 330 K or 57.26 ˚C

Now heat given by the flue gas = Heat taken by the bagasse
$mC_p\ [T_{gi}-T_{go}] = mC_b\ [T_{bo}-T_{bi}]$
7.56x.23 [200-T_{go}] = 7x.416 [57.26-35]

Temperature of flue gas after heat rejection:

T_{go}=163.2 ˚C

4.3 Moisture Reduction of Bagasse

Enthalpy decrease in flue gas = m_g x C_{pg} x $[T_{gi}-T_{go}]$
Enthalpy increase in dry bagasse = m_b x C_{pb} x $[T_{bo}-T_{bi}]$ [9], Enthalpy increase in moisture = $M_f h_2$ + [M-M_f] x h_{go} – Mh_1, Where M, Mf = initial and final moisture content in the bagasse at the temperature T_{bi}, T_{bo} .h_1, h2, hgo = specific enthalpies of H_2O at temperature T_{bo}, T_{bi}, T_{go}.
h_1= 146.7 kJ/kg, h_2= 239.44 kJ/kg, h_{go}= 2758.9 kJ/kg data taken by steam table.

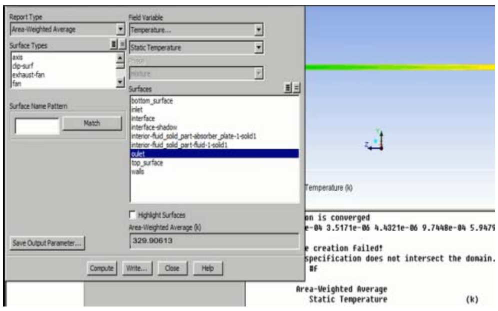
4.4 The Energy Balance eq. for the Bagasse Dryer

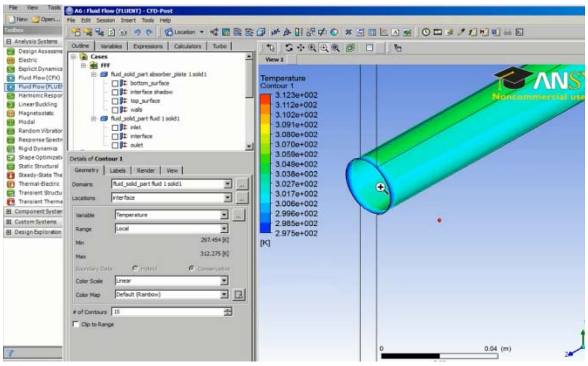
[9] mg x C_{pg} x $[T_{gi}-T_{go}]$ = m_b x C_{pb} x $[T_{bo}-T_{bi}]$ + $M_f h_2$ + [M-M_f] x h_{go}–Mh_1

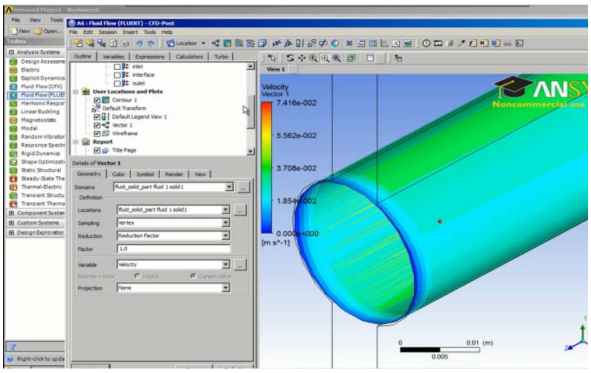
4.5 Final Moisture of Bagasse

M_f = [m_g x C_{pg} x $[T_{gi}-T_{go}]$ - m_b x C_{pb} x $[T_{bo}-T_{bi}]$ + Mh_1 - Mxh_{go}] / [h_2-h_{go}],M_f = [7.57 x .23 x [200-163.35] – 7 x .461 x [57.2-35]+ 0.5 x 146.7- 0.5x 2761]/ [239.44 - 2761],**M_f = 0 .46 0r 46 %** Moisture % after drying bagasse Mf =0.46 0r 46 %After drying bagasse 4 % moisture reduced.1 % moisture reduction increases 196 kJ/Kg,GCV thus Total increased GCV is = 4x196 =784 kJ/kg**.**In general 1% reduction in moisture in bagasse increased 0.5% efficiency of boiler thus boiler efficiency increased from 77% to 79% theoretically.

5. Result of thermal analysis of dryer by ANSYS







6. Calculation of Efficiency of Dried Bagasse Boiler

Boiler efficiency= [Q x (h_g-h_f) / q x GCV] x 100= [140 x (3562-398) / 70 x 9900] x 100Value of $h_{g\ \text{at}\ 190°C\ \text{and}\ 42.1\ \text{bar}}$ &$h_{f\ \text{at}\ 90°C}$ calculated by the interpolation method by using steam table. Boiler efficiency (using dry bagasse) = 0.8 or 80 % **Increased boiler efficiency = 80-77 = 3%**

7. Benefit Expected After Dryer Installation

NCV of bagasse at 50% moisture =1800kcal/kg, NCV of bagasse at 46% moisture =1900kcal/kg, Energy available at 50% moisture bagasse of 70 TPH =126,000000kcal/hr, Energy available at 46% moisture bagasse of 70 TPH =13, 30,00000kcal/hr

Excess energy available after drying =13, 30, 00000-126, 000000= 70, 00000 kcal/hr, Unit of power that can be produced by that excess energy, 1 kcal/hr = 0.0011627 KW.hr, Thus 70, 00000 kcal/hr = 8139 KW.hr, Steam power consumption due to dryer = 120 KW.hr, Net extra power available = 8139-120 = 8018.9 KW.hr

Extra revenue: @ A conservative rate of Rs. 3 unit = 8018.9 x 5x 24 = 962268 Rs. /day=17, 28868040 Rs. /month, If plant will run for 90 days = 86604120 Rs. / 90 days

8. Result: Dryer Dimensions:

Diameter =0.75 m,Length = 8 m,The internal heat transfer coefficient = 18.6 W/m^2/K,External heat transfer coefficient = 22.31 W/m^2/K,The thermal conductivity of air at 25°C is: k= 0.02442+(0.6992×10^{-4}×25) = 0.0384 W/m/K,Velocity of flue gas =9 m/s ,Overall heat transfer coefficient U = 0.746 ,Reynolds no. = 210900, Nusselt no. = 363, Kinematic viscosity = 0.000032 $m^{2/}$ material of dryer =mild steel Efficiency of the boiler using coal is = 77 %,Moisture % after drying bagasse M_f =0.46 0r 46 %,Efficiency of the boiler using dry bagasse is= 80 %,Temperature of flue gas after heat rejection= 163.2 °C,Temperature of bagasse after drying = 57.26°C,Unit of power that can be produced by that excess energy 70, 00000 kcal/hr = 8139 KW.hr,Net extra power available = 8018.9 KW.hr,Extra revenue If plant will run for 90 days = 51,962472 Rs. / 90 days .No. pollution due to zero % sulfur contain in bagasse.

9. Conclusion

The aim of the introduction of the dryer was to reduce the biomass moisture content in order to improve boiler efficiency and reduce device costs. The results obtained show clearly that these aims were succeeded. The boiler efficiency was improved from 77 to 81 %.

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Author Profile

Sankalp Shrivastava received the Bachelor of Engineering Degree in mechanical Engineering from jawahar Lal Institute of Technology in 2000 respectively. Currently he is doing Master of Engineering in Thermal and Design from Institute of Engineering and Technology, Devi Ahilya Vishaw Vidhayalay, Indore, India