ENERGY AND EXERGY ANALYSIS OF SHAKARGANJ LIMITED JHANG THERMAL POWER PLANT

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ABSTRACT

Exergy analysis has sparked interest within the scientific community to require a more in-depth check up on the energy conversation devices. Exergy analysis gives entropy generation, irreversibility percentage exergy loss and second law efficiency. The exergy loss or irreversibility is the maximum at boiler. Thus to know about actual flow of exergy in the cycle thermodynamic analysis based on second law is desirable. In this report exergy analysis of operating condition of boiler has been carried out based on mass and exergy balance. The power plant boiler was simulated based on the measured operating data and the thermodynamic states of the plant components. . It has been found that maximum exergy destruction occurs due to combustion process. Exergy efficiency of boiler according to second law analysis and the exergy analysis of back pressure steam turbine is performed. It is found that at minimum flue gas outlet temperature second law efficiency is the maximum.

INTRODUCTION

Steam Boilers

Pressure 25 bar & Temperature 350 ^{o}C

Boiler #	Make	MCR T/H	NCR T/H
Boiler # 1	Babcock & Wilcox	40	35
Boiler # 2	Babcock & Wilcox	80	72
Boiler # 3	Yoshimine (IFL)	80	72
Boiler # 4	Yoshimine (IFL)	80	72
Boiler # 5	Yoshimine (Brother)	80	80

Power House Steam Turbines:

Pressure 25 bar & Temperature 335 ^{o}C

TG-Set #	Make	Design Exhaust Pressure & Temperature	Specific Steam Consumption Kg/KWH	Capacity
TG-Set – I	Qingdao China	Back Pressure 1.5 bar, Temp. 160 ^{o}C	10.5	6 MW
TG-Set – II	Qingdao China	Back Pressure 3 bar, Temp. 185 ^{o}C	12.6	6 MW
TG-Set – III	KKK Germany	Back Pressure 1 bar, Temp. 160 ^{o}C	14	2 MW

Steam Turbine Energy & Exergy Analysis:

Energy input is equal to product of mass of steam into turbine and its enthalpy at entry: $\dot{E}i = \dot{m}i \times hi$

Energy output is sum of heat extracted and heat exhausted.

$\dot{E}o = (\dot{m}ext \times hext) + (\dot{m}exh \times hexh)$

Work done is equal to the energy in steam at entry to turbine minus that at exit.

$W.D = \dot{E}i - \dot{E}o$

Energy Efficiency (1st Law efficiency) of Turbine :

η I = (Actual Power Develop by Turbine Shaft) / ($\dot{E}in - \dot{E}out$)

Exergy Input : $\Psi in = \dot{m}s (hs - T0ss)$

2. Exergy Out : $\Psi out = \dot{m}ext (hext - T0Sext) + \dot{m}exh (hexh - T0Sexh)$

Exergy Destruction in Turbine: $\Psi des = \Psi in - \Psi out - \Psi power$

Inlet Conditions:

	Case#1	mf in Steam	Pressure	Temperature
		kg/s	Kpa	C
Impulse Steam Turbine TG-2 - 02 MW Back Pressure- 180 Kpa	1	3.69	2400.00	341.00
	2	3.72	2400.00	346.00
	3	3.81	2400.00	342.00
	4	3.89	2400.00	341.00
	5	4.03	2400.00	346.00
	6	4.25	2400.00	346.00
	7	4.08	2400.00	346.00
	8	4.03	2400.00	347.00

Enthalpy	Entropy	To (38 C)	Energy in	Exergy In
KJ/kg	Kj/kg.k	C	KW	KW
3108.58	6.83	311.00	11484.48	3636.33
3120.02	6.85	311.00	11613.41	3684.78
3110.87	6.83	311.00	11838.59	3750.01
3108.58	6.83	311.00	12088.92	3827.72
3120.02	6.85	311.00	12566.75	3987.26
3120.02	6.85	311.00	13260.09	4207.25
3120.02	6.85	311.00	12740.08	4042.26
3122.30	6.85	311.00	12575.94	3991.84

Outlet Condition

mf-out	Pressure	Temperature
kg/s	Kpa	C
3.69	180.00	190.00
3.72	180.00	174.00
3.81	180.00	169.00
3.89	180.00	168.00
4.03	180.00	172.00
4.25	180.00	171.00
4.08	180.00	171.00
4.03	180.00	172.00

Enthalpy	Entropy	Energy out	Exergy out
KJ/kg	Kj/kg.k	KW	KW
2851.65	7.52	10535.27	1900.30
2819.42	7.44	10494.50	1876.60
2809.31	7.42	10690.97	1907.05
2807.28	7.42	10917.20	1946.48
2815.38	7.44	11339.71	2025.72
2813.35	7.43	11956.75	2134.90
2813.35	7.43	11487.86	2051.18
2815.38	7.44	11339.71	2025.72

Exergy Analysis:

Work Done	Generator Power Output	1st Law Efficiency	Exergy Destruction	2nd Law Efficiency
KW	KW	%	KW	%
949.21	930.00	97.98	8634.96	16.80
1118.91	960.00	85.80	8617.90	17.26
1147.62	980.00	85.39	8783.92	17.32
1171.72	990.00	84.49	8970.72	17.15
1227.04	1020.00	83.13	9313.99	16.96
1303.33	1080.00	82.86	9821.85	17.03
1252.22	1100.00	87.84	9436.68	18.05
1236.23	1050.00	84.94	9313.99	17.45

1. **Boiler Energy and Exergy Analysis**

Composition of Bagasse

Composition of bagasse.						
	C%	H%	O2%	Ash %	Moisture	Total %
Composition of dry bagasse i.e 0% moisture	47	6.5	44	2.5	0	100
Composition of wet Bagasse with 50% moisture	23.5	3.25	22	1.25	50	100
Composition of wet Bagasse with 48% moisture	24.44	3.38	22.88	1.3	48	100

Composition of dry bagasse is,

C = 47 %
H2 = 6.5 %
O2 = 44 %
Ash = 2.5 %
Total = 100 %

And Composition of wet Bagasse with 50% moisture is,

C = 0.47x50 = 23.50 %
H2 = 0.065x50= 3.25 %
O2 =0.44x50= 22 %
Ash = 0.025 x50 = 1.25 %
Moisture= 50 %.
Total =100 %

Bagasse combustion calculation:

O2 required for complete combustion per Kg of Bagasse

$C + O_2 = CO_2$ 12 + 32 = 44 (32/12) x 0.2256 = 0.6016 Kg
$2H_2 + O_2 = 2H_2O$ 4 + 32 = 36 (32/4) x0.0312 = 0.2496
Total O2 required. =0.6016 + 0.2496 – 0.2112 = 0.64 Kg/Kg

Air required for Bagasse

Air Required for complete comb = (100/23)x 0.64 = 2.783 Kg/Kg
Excess air coefficient (RA) =1.45
Total Air Supply =2.783x 1.45 = 4.035 Kg/Kg

Product of combustion per Kg of Bagasse.

CO2. (44/12) x0.2256 = 0.8272 Kg

H_2O. (36/4) x 0.0312 = 0.2808 +0.52 = 0.54
O_2. 4.035 x 0.23 -0.64 = 0.28805 Kg
N_2. 4.035x0.77 = 3.10695 Kg

Gas Produced by 1 Kg of Bagasse.
0.8272+0.54+0.28805+3.10695 = 4.7662 kg/kg
Composition of gas by weight
CO_2 = (0.8272/4.7662)x100= 17.4 %
H_2O = (0.54/4.7662) x 100= 11.3 %
O_2= (0.28805/4.7662)x100= 6.0 %
N_2 = (3.10695/4.7662) x 100 = 65.3 %

O2 required for complete combustion per Kg of Bagasse						
Bagasse Quality	% O2 For CO2	% O2 For H2O	O2 in fuel	Required O2(kg/kg)	Air Req (kg/kg)	Total Excess Air (kg/kg)
Total O2 Required for 52% Moisture Bagasse	0.602	0.250	0.2112	0.640	2.783	4.0347826

Product of Combustion						
	Moisture %	CO2	H2O	O2	N2	Gas Produced/kg of Bagasse
52% Moisture Bagasse	52	0.8272	0.8008	0.288	3.107	5.022782609

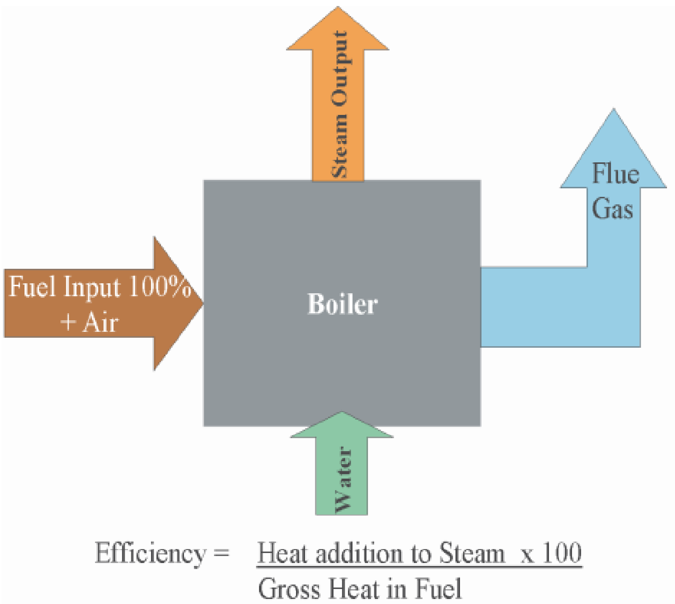
Boiler Efficiency Calculation:

A simple method to measure the efficiency is to calculate the steam fuel ratio, i.e. is to measure the steam generated by unit mass of fuel. Steam fuel ratio, is directly proportional to boiler efficiency. Following ratios can be obtained for different fuels.

Coal	5.7
Rice Husk	4.0
Bagasse	2.2

Boiler Efficiency=

This method is known as direct method which is based on simply that efficiency is equal to output divided by input. The other method is the indirect method of calculating boiler efficiency.



To account the boiler losses a more better and precise formula for efficiency calculation is given below:

η= x100

Where,
Mv = Heat transfer to steam per kg of bagasse burnt
NCV =Net calorific value
Also,

Mv= (N.C.V-Q).α.β.γ
Where
Q = Sensible heat loss in flue gas
α.β.γ = Co-efficient of x-tics of combustion efficiency
α = Co-efficient representing heat loss due to un-burnt solids.
β = Co-efficient to account for heat losses by radiation.
γ = Co-efficient of incomplete combustion.

For spreader stoker furnaces, its normal value α is taken as 0.975.
This value varies from 0.95 to 0.99 for more or less efficient lagging. Its value is taken as β 0.97.
Its value is taken as γ 0.95

Whereas,

Q= [(1-M) x (1.4RA-0.13) + 0.5] t

Where,
M = % Moisture in Bagasse
RA =Ratio of excess Air
t =Temperature of Flue gases

Here RA is ratio of excess air usually taken 1.45 for bagasse.
A better estimation of efficiency can directly be found by calculating the highest loss in Boiler which is sensible heat loss in flue gases in Kcal/Kg of Bagasse.
The calorific value of bagasse in relationship to moisture and Pol is given below,

Bagasse Quality	Net Calorific Value (kcal/kg)	Moisture	Pol
52% Moisture Bagasse with Pol 2.0 %	1704	52	2
50% Moisture Bagasse with Pol 2.0 %	1801	50	2
48% Moisture Bagasse with Pol 2.0 %	1898	48	2

Flue Gas outlet temperature Tout (C)	Loss of Sensible Heat Q (Kcal/kg of bagasse) burnt 52% Moisture Bagasse with Pol 2.0 % NCV 1704 kcal/kg
180	241.99
190	255.44
200	268.88
210	282.32
220	295.77
230	309.21
240	322.66
250	336.10
260	349.54
270	362.99

After calculation of sensible loss, heat transfer to steam can easily be found by,

Flue Gas outlet temperature Tout (C)	Mv , Heat transfer to steam/ kg of Bagasse burnt 52% Moisture Bagasse with Pol 2.0 % NCV 1704 kcal/kg
180	1313.56
190	1301.48
200	1289.40
210	1277.32
220	1265.24
230	1253.16
240	1241.09
250	1229.01
260	1216.93
270	1204.85

Bagasse efficiency is calculated by: using the equation:

η II = x100

In indirect method the amount of different losses is worked out or measured and finally the summation of losses is subtracted from 100.

Both methods are equally good and recognized for calculating boiler efficiency.

In second method losses are calculated, when every loss is known one can find that which loss is major contributor for efficiency loss and can take the corrective measure to reduce it. One cans decide which loss is less and can be ignored. On focusing the important one boiler efficiency can be improved.

Flue Gas outlet temperature Tout (C)	Boiler 2nd Law Efficiency
	52% Moisture Bagasse with Pol 2.0 %
	NCV 1704 kcal/kg
180	77.09
190	76.38
200	75.67
210	74.96
220	74.25
230	73.54
240	72.83
250	72.12
260	71.42
270	70.71

Results and Conclusion:

A detailed mathematical model has been established to calculate the effect of below mentioned parameters on the efficiency of Bagasse fired boilers.

Bagasse Moisture
Bagasse Pol
Flue Gas Temperature
Feed water Temperature

Retrofitting is used to alter the above mentioned parameters which directly influence the boiler operating efficiency which is linked to fuel consumption. Thus by installing retrofits, we can optimize the boiler efficiency and can save tons of fuel.

Various retrofits are used for specific purpose like

Bagasse Moisture
Could be reduced by optimize milling and Bagasse dryer
Bagasse Pol
Could be reduced by optimize milling operation
Flue Gas Temperatur
Could be reduced by utilizing the available heat by economizer, Air Preheater, Re-heater and Bagasse dryer
Feed water TemperatureCould be increased by economizer

After detailed calculations the relationship of bagasse consumption for steam generation has been found as per below table. For constant steam generation rate at isobaric and isothermal steam generation, bagasse consumption is variable and fully dependent on following,

Feed Water temperature
Fuel heating value
Flue gases outlet temperature

At 350 C and 25 Bar-a Steam and 110 C Feed water Temperature							
52% Moisture Bagasse with Pol 2.0 %							
m(s) Kg	h(s) Kj/kg	h(w) kj/kg	N.C.V kj/kg	Flue Gas Tout (C)	Efficiency %	Qty of Fuel (kg)	Steam/Bagasse Ratio (kg/kg)
80000	3127	463	7130	180	77.08681706	38775.24618	2.063171943
80000	3127	463	7130	190	76.37795967	39135.11596	2.044199897
80000	3127	463	7130	200	75.66910229	39501.72816	2.02522785
80000	3127	463	7130	210	74.9602449	39875.27405	2.006255804

80000	3127	463	7130	220	74.25138752	40255.95223	1.987283758
80000	3127	463	7130	230	73.54253013	40643.96891	1.968311711
80000	3127	463	7130	240	72.83367275	41039.53839	1.949339665
80000	3127	463	7130	250	72.12481536	41442.88333	1.930367618
80000	3127	463	7130	260	71.41595798	41854.23529	1.911395572
80000	3127	463	7130	270	70.70710059	42273.83507	1.892423526

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