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Exergy Analysis of 4.5mw Biomass Based Steam Power Plant

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Abstract: *Exergy analysis provides a mean to evaluate the degradation of energy during a process,the entropy generation,the lost of opportunities to do work and offers an another approach for improvement of power plant performance.This paper present work Biomass based steam power plant(BBSPP) the results of an exergy analysis performed on a 4.5MW steam power plant in Karempudi.The results of the exergy analysis indicate that the boiler produces the highest exergy destruction .Exergetic efficiency is compared with Thermal Efficiency(based on Energy) and it is observed that thermal efficiency of the plant about 18.25%andexergeticefficiencyis 16.89%.*

Keywords: *Exergy, Anergy, Biomass, Boiler, Turbine, Condenser, Feed Pump.*

NOMENCLATURE

H	Enthalpy
S	Entropy
E	Exergy
Q_R	Heat Input
Q_{CH}	Chemical Energy of Fuel
EQ_{CH}	Chemical Exergy
∇e_B	Loss of Exergy in Boiler
∇e_T	Loss of Exergy in Turbine
∇e_C	Loss of Exergy in Condenser
η_{th}	Thermal Efficiency of the plant
η_e	Exergy efficiency of plant
η_b	Efficiency of boiler
η_{eb}	Exergeticeffeciency of the boiler
f	1.08(solid fuel as shown by szargut)

Subscripts (State Points in Rankine Cycle):
1.Boiler 2. tubine
3.condenser 4.feed pump

I. Introduction

Biomass Based Steam Power plants use fuels like Rice husk, Groundnut shell, Fire wood, coconut and other Agro waste & Municipal solid waste (instead of conventional fuels like coal) burnt in biomass fired boiler to generate steam at high pressure. Due to the rapid depletion of conventional fuels there is increasing demand for using renewable sources of energy and use of biomass seems to be an alternative to conventional fuels in generating power. The object of this paper is to discuss Rankine Cycle and to introduce exergy analysis of Rankine cycle to enable us to find exergetic efficiency and component-wise losses. The analysis uses parameters of a working biomass based steam power plant of 4.5MW capacity.

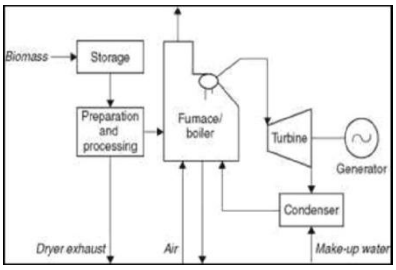

Figure 1: Layout of a BBSPP

II. Literature Survey

Most of the plants are analyzed and reported in literature are pertaining to either plants of more than 100 MW capacity or it is less than 1MW capacity. Plants of the capacity less than 1 MW are mostly of academic interest and outcome of the reports indicate the total efficiency. As per the recent studies conducted on exergy analysis of plants are either directly coal fired plants or large capacity gas turbine plants [Kotas]. As on today to overcome the fast depletion of fossil fuels and support the renewable energy options for powergeneration there is a scope for biomass based power plants.Biomass can be used for either direct combustion in the specially designed waste recovery boiler or can be converted into useful syn gas by Thermo chemical gasification. Gasification is again a differentstream of process where solid fuel is directly converted into gaseous fuel of mostly CO and H_2. This gas has a lower calorific value due to dilution of Nitrogen in the gas [G.S.Sharma et al]. Direct firing of the biomass in the boiler for generation of the steam is a commercially viable option for power plants engineers. The reason for this statement is that only conventional fuel is replaced by biomass. The quantity of biomass may vary from conventional coal in the boiler as the calorific value of the biomass is less than coal. There are various aspects to be considered in direct firing of the biomass in boilers such as high moisture content of the fuel, corrosive ash content and emissions.

Most of the literature published claims the thermal efficiency of the thermal plants are about 33% in India where as in the global scenario it is as high as 45% .Attaining higher efficiencies need investigation of available energy at all salient points of operation of the plant. The depletion of available energy (exergy) is due toincrease in entropy [van wylen] or more practically due to irreversibility in the thermodynamic system. This paper states the need of exergy analysis to BBSPP which helps in improving the efficiency of the plant

III. Operating Parameters

For exergy analysis, the following operating parameters are used.

Table 1 : Operating Parameters

S.No	Component	Pressure (bar)	Temperature (^{o}c)
1	Boiler	80	280
2	Turbine	65	485
3	Condenser	0.89	50
4	Feed Pump	0.89	100

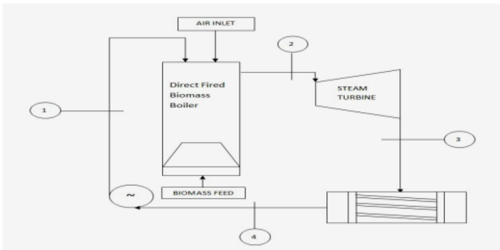

Figure 2: P&I Diagram

EXERGY ANALYSIS OF BIOMASS BASED STEAM POWER PLANT

When we study a thermal system, we would like to know how good the system is and how much energy it consumes. For this purpose, we can imagine an ideal system i.e. a system that uses reversible processes and compare it with the actual system to find its performance. According to Second Law of Thermodynamics we understand that energy can be divided into 2 parts:

1. Available Energy (Exergy)
2. Unavailable Energy (Anergy)

A. Boiler

Combustion of fuel is highly irreversible process. Moreover, the heat transfer from the flue gases to the water takes place with a large temperature difference. Hence, heat transfer also is a highly irreversible process. Therefore, considerable degradation of energy takes place in the boiler.

The loss of exergy in boiler is given by

Q_R =H2 - H1 (1)

∇E_S =E2 - E1 (2)

EQ_{CH}=F*(Q_{CH} (3)

∇E_B=EQ_{CH} - ∇E_S (4)

$\eta_B = Q_R / Q_{CH}$ (5)

$\eta_{EB} = Q_R/EQ_{CH}$ (6)
$E^*_{CH}(fuel) = \beta.(LHV)$ (7)

The Loss of exergy in boiler consists of 2 parts,
i.e.

1. Due to incomplete combustion and incomplete recuperation of flue gases.
2. The temperature restriction of steam restricts the maximum exergy that can be given to the steam.

The Boiler Efficiency is about 75.69%. The
exergetic efficiency of the boiler is 70.08%.

B. Turbine

The steam flowing through the turbine passages has to overcome friction. There is considerable turbulence in the high velocity stream. This results in loss of exergy. The efficiency of the turbine is the ratio of actual work done and the isentropic work done bturbine. The efficiency of the turbine comes out to be 88%.
The loss of Exergy in the turbine is given by
$\nabla E_T = (E_2 - E_3) - W_T$ (8)

C. Condenser

Large quantity of heat is removed from the condenser by cooling water. The heat rejected by the condenser is more or less worth less and cannot be judged for the performance of the condenser.

The Loss of Exergy in the condenser is given by
$\nabla E_C = E4 - E3$ (9) (9)

D. Feed Pump

Part of the work done by the pump is lost in friction. However pumping work itself is often negligible. Thus we assume the pumping losses to be negligible. The work done by pump is assumed to be zero.

RESULTS

Exergy analysis of a 4.5MW BBSPP is performed and exergy values at all locations are investigated. It is observed that exergetic efficiency of the overall plant is 16.89% and overall thermal efficiency is about 18.25%. The difference of 1.36% is destruction of available energy is observed.

Table 2 : Properties Of Steam

State	Enthalpy (KJ/Kg)	Entropy (KJ/KgK)	Exergy (KJ/Kg)
1	1027.83	2.45	957
2	3380.97	6.79	3178.5
3	2402.9	6.85	2193.6
4	401.3	1.23	366.06

In exergy analysis of BBSPP the exergies of boiler, turbine, and condenser are calculated and their losses in exergy are calculated as shown in table 3 and 4. It is observed that maximum loss of exergy (Anergy) occurs at the boiler. The boiler losses can be minimized by using Losses can be still reduced when the pumping all relevant air condensation process, i.e. by maintaining low vacuum and dissociating gases in condenser, the losses can be still reduced if proper condensation of flue gases cooling is adopted.It can be seen that the maximum exergy destruction occurs in the boiler with a value of 49.17% of the totalexergy destruction. It seems obvious from the data in that the irreversibility associated with chemical reactionsis the main source of exergy destruction.

Table 3 :Exergy and Anergy Calculations

S. No	Components	Condition Exergy (Inlet)	Exergy (Outlet)	Exergy Destruction	Anergy (KJ/Kg)
1	Boiler	6200.95	3151.51	49.17	3049.44
2	Turbine	3151.51	2125.93	32.54	1025.58
3	Condenser	2125.93	1312.07	38.28	813.86
4	Feed Pump	1312.07	1037.83	20.90	274.24

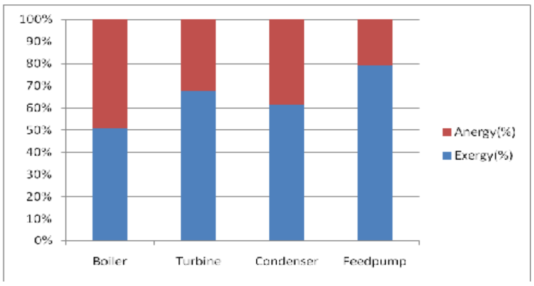

Figure3:Graphical Representation of Exergy Destruction

Table 4 : Overview Of Results

Heat Supplied By Fuel q_{ch}	3680 KJ/Kg
Exergy Supplied By Fuel eq_{ch}	3974.4 KJ/Kg
Thermal Efficiency η_t	18.25%
Exergy Efficiency η_e	16.89%
Exergetic Efficiency of Boiler η_{eb}	70.08%
Total Loss of Exergy in Boiler ∇e_b	2554.44 KJ/Kg
Loss of Exergy in Turbine ∇e_T	126.25 KJ/Kg
Loss of Exergy in Condenser ∇e_C	1825.54 KJ/Kg

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