Theoretical Investigations on Entropy Generation and Work Lost Analysis of 4MW Rice Husk Fired Thermal Power Plant

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Abstract

Global survival and human comfort in now a day strongly depend upon energy and environment. In this research generalized thermodynamic model equations were subjected to 4MW rice husk fired thermal power plant in Pakistan for theoretical investigations on work lost and entropy generation to check the plant thermal performance and irreversibility's and concluded that the entropy generation and work lost is highest in Furnace/Boiler that is 3487.12352 KWK^{-1} and 1039.685×10^3 respectively. The work lost in Furnace/Boiler is about 32.4641% while the overall efficiency of the power plant is 59.8917%.

Keywords: Thermal Power Plants, Thermal and Energy Analysis, Thermal Performance, Work Lost.

Introduction

Due to unavailability of high rank coal, low rank and cheap coal is burned by a majority of thermal power plants that leads to thermal efficiency losses in furnace/boilers. Thermal energy and high boiler losses are caused by low rank coal. Steam power plants are widely used in the world for the electricity generation. Energy consumption and production is one of the most important factors showing the development stages of nations. Currently natural gas, coal, and petroleum fired thermal power plants accounts for 80% world electricity production and remaining 20% electricity is produced by using other different sources such as nuclear, hydraulic, wind, solar, geothermal and biogas etc. According to the US Energy Information Administration EIA there is a dramatically increase in the Energy Production by the installation of Thermal Power Plants during (1980-2006) tabulated in Table 1.

Table 1: Fuel Types for Energy Generation

Fuel Type	1980	2004	2006
Oil	4.38	5.58	5.74
Gas	1.80	3.45	3.61
Coal	2.34	3.87	4.27
Hydroelectric	0.60	0.93	1.00
Geothermal, Wind Energy, Solar Energy, Wood	0.02	0.13	0.16
Nuclear Power	0.25	0.91	0.93
Total	9.48	18.0	15.8

Currently a number of techniques has been developed which are being used in order to increase the efficiency of thermal power plants. One of the most outstanding methods to reduce cycle irreversibility is reheating. It increases the efficiency by increasing the temperature and addition of heat and also by increasing the steam temperature at inlet and by increasing the efficiency of expansion process in the steam turbine [1-3]. Energy consumption is the most important problem in today. In the present era the level of development of nations is determine by the per capita energy consumption. Generally by using the first law of thermodynamics the energy performance of a thermal power plant can be evaluated while the exergy analysis can be performed on the basis of 2nd law of thermodynamics which is useful in evaluation, optimization, design and performance improvements of thermal power plant [4-6].

Thermodynamic analysis is a technique, 3rd step in system analysis which is useful in finding out the irreversibility's in the system, losses of energies, entropy generation and work lost by using a mathematical formulation based upon 1st law and 2nd law of thermodynamics in order to improve the performance of existing processes and development of new optimize, economic and environmental friendly processes by using the concept of conceptual design i.e. material and energy balances [7-12]. Thermodynamic analysis is only helpful in finding the efficiency loss and energy loss it cannot tell us that how a process can be improved however it can point out that which part of the process or systems have imperfections, irreversibility's, energy loss, efficiency loss, entropy generation and work lost so that it can be improved sometimes simple energy analysis are not sufficient in order to point out the system imperfections so in such cases we use exergy analysis to point out the system imperfections [13-20]. Thermal power plants are used for the generation of power and electricity through the interaction of various electrical and mechanical equipment's but the core unit of the thermal power plants is furnace/boiler. Previous research shows that due to the combustion process which is itself entropy generation process, the furnace/boiler in thermal power plants accounts for largest energy and exergy losses and these losses can be reduced by maintaining optimum air to fuel ratio for complete combustion and pre-heating of combustion air. Previous research also shows that the energy and exergy efficiency of furnace/boiler integrated with thermal power plants are 89.21% and 45.48% respectively [21-23,33]. Researchers focus their interest on the energy and exergy analysis of thermal power plants because it is helpful in finding out the irreversibility's in the system, losses of energies, entropy generation and work lost and their energy and exergy analysis shows that majority of imperfections are found in furnace/boiler, super heaters, economizers and air pre-heaters [24-25]. Several researches shows that the efficiency of thermal power plants can be increased by increasing the

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furnace/boiler pressure, superheating steam to a very high temperature, decreasing flow rate of steam, decreasing the condenser pressure, feed water pre-heating, by reducing the imperfections in steam generator, reducing excess air, reducing stack gas temperature and by increasing steam pressure [26-34].

Rice husk a major by-product of the rice milling industry, is one of the most commonly available lignocellulosic materials that can be converted to different types of fuels and chemical feed stocks through a variety of thermochemical conversion processes. Rice husk is one of the most widely available agricultural wastes in many rice producing countries around the world. Globally, approximately 600 million tons of rice paddies are produced each year. A typical analysis of rice husk is given in Table 2.

Table 02: Typical Analysis of Rice Husk

Property	Range
Bulk density (Kg/m^3)	96-160
Hardness (Mohr's Scale)	5-6
Ash, %	22-29
C, %	35
H_2, %	4-5
O_2, %	31-37
N_2, %	0.23-0.32
S, %	0.04-0.08
Moisture, %	8-9

Experimental Work

The operational data obtained from the rice husk thermal power plant operating in Pakistan including specification, pressure conditions, and temperature conditions are tabulated in Table 3, Table 4, and Table 5: as follows. The conditions and properties of steam in the cycle are given below in Table 05: taken by using steam table by interpolation methods.

$$\frac{H_R - H_L}{H_H - H_L} = \frac{S_R - S_L}{S_H - S_L} = \frac{P_R - P_L}{P_H - P_L} \qquad (1)$$

Table 03: Specification of Rice Husk Fired Thermal Power Plant

Parameter	Value
Electrical Power	4 MW (Design) 1.2-7 MW (Operational)
Voltage	11 KV
Fuel Flow Rate	8 TPH (Design) 3-4 TPH (Operational)
Steam Flow Rate	30 TPH (Design) 10-12 TPH (Operational)
Furnace Inside Temperature	550-600 ºC
Turbine Speed	9700 rpm

Table 04: Pressure Conditions of Rice Husk Fired Thermal Power Plant

Equipment	Inlet Pressure	Outlet Pressure
Furnace/Boiler	60 Bar (Design) 51 Bar (Operational)	59.5 Bar (Design) 50.5 Bar (Operational)
Turbine	59 Bar (Design) 50 Bar (Operational)	0.08 Bar (Design) 0.08-0.11 Bar (Operational)
Condenser	0.08 Bar (Design)	0.08 Bar (Design)
Pump	0.08 Bar (Design)	60 Bar (Design) 51 Bar (Operational)

Table 05: Temperature Conditions of Rice Husk Fired Thermal Power Plant

Equipment	Inlet Temperature	Outlet Temperature
Furnace/Boiler	25 ºC	400 ºC
Turbine	380-400 ºC	42-45 ºC
Condenser	45 ºC	30 ºC
Pump	25 ºC	25 ºC

Using the Rice Husk as a furnace fuel the combustion results following reactions their heat of reactions and entropies are calculated using C4 data table and summarized data in Table 6 and Table 7: as follows.

Table 06: Properties of Steam at Different Inlets and Outlets

State of Steam	Temperature (ºC)	Pressure (KPa)	Enthalpy (KJ/Kg)	Entropy (KJ/Kg. K)
Sub-Cooled Liquid	45	6000	1213.7	3.0273
Superheated Vapours	800	5900	3657.0	7.1749
Wet Vapours	45	8	2561.1	8.3357
Saturated Liquid	45	8	96.925	0.528

Table 07: Properties of Rice Husk Combustion

Reactants	Products	$\Delta H_{298.15}$ (J)	$\Delta G_{298.15}$ (J)
$C + O_2$	CO_2	-393,509	-394,359
$2C + O_2$	$2CO$	-110,525	-137,169
$N_2 + 2O_2$	$2NO_2$	33,180	51,310
$S + O_2$	SO_2	-296,830	-300,194
Total		-767,684	-780,412

Whence the entropy can be calculated using this relation

$$\Delta S^{o}{}_{298} = \frac{\sum \Delta H^{o}{}_{298} - \sum \Delta G^{o}{}_{298}}{298.15} = 42.6899\, JK^{-1}$$

On the basis of 1mole of Rice Husk when fired with 50% excess air the air.

$$O_2: \ (5)(1.5) \ = 7.5\, mole$$

$$N_2: \ (7.5)\left(\frac{79}{21}\right) \ = \ 28.21425\, mole$$

$$Total \ = \ 35.71425\, mole\ of\ air$$

After the complete combustion of Rice Husk the flue gas contains are tabulated in Table 8:

Table 8: Properties of Flue Gases

Components	Moles	Mole Fraction
CO_2	1	0.028
CO	2	0.056
NO_2	2	0.056
SO_2	1	0.028
O_2	2.5	0.070
N_2	27.21425	0.761
Total	37.71425	0.999 ~ 1.000

$$\Delta S_a = nR \sum_i y_i \ln y_i \qquad (2)$$

Step a: Pre-Combustion Step

$$\Delta H_a = 0 \qquad (3)$$

$$\Delta S_a = nR \sum_i y_i \ln y_i \qquad (4)$$

$$\Delta S_a = (35.71425)(8.314)(0.21 ln 0.21 + 0.79 ln 0.79)$$

$$\Delta S_a = -152.5914 JK^{-1}$$

Step b: Combustion at surface temperature of 298.15K

$$\Delta H_b = \Delta H^{o}{}_{298} = -767{,}684\, J$$

$$\Delta S_b = \Delta S^{o}{}_{298} = 42.6899\, JK^{-1}$$

Step c: Formation of Flue Gases

$$\Delta H_c = 0 \qquad (5)$$

$$\Delta S_a = nR \sum_i y_i ln y_i \qquad (6)$$

$$\begin{aligned} \Delta S_a = (-35.71425)(8.314)(&0.02800 ln 0.02800 \\ &+ 0.05600 ln 0.05600 \\ &+ 0.05600 ln 0.05600 \\ &+ 0.02800 ln 0.02800 \\ &+ 0.07000 ln 0.07000 \\ &+ 0.76199 ln 0.76199) \end{aligned}$$

$$\Delta S_a = 272.0456 JK^{-1}$$

Step d: Steam Generation Step

The mean heat capacities between the 298.15K and 755.75K are calculated for flue gas components as follows. In order to calculate the mean heat capacities some useful data is given in **Table 09:** By using following equations the means heat capacities and entropies are calculated and tabulated in **Table 10:**

$$\frac{(C_p)_H}{R} = A + \frac{B}{2} T_o(\tau + 1) + \frac{C}{3} T_o{}^2(\tau^2 + \tau + 1) + \frac{D}{\tau T_0{}^2}$$

$$\frac{(C_p)_S}{R} = A + \left[BT_o + \left(CT_o{}^2 + \frac{D}{\tau^2 T_0{}^2}\right)\left(\frac{\tau+1}{2}\right)\right]\left(\frac{\tau-1}{\ln\tau}\right) \qquad (7)$$

Table 09: Useful Data for the Calculation of Mean Heat Capacities of Flue Gas Components

Components	A	B	C	D	Temperature Range (K)
CO_2	5.457	1.045×10^{-3}	0	-1.157×10^{5}	298-2000
CO	3.376	0.557×10^{-3}	0	-0.031×10^{5}	298-2000
NO_2	4.982	1.195×10^{-3}	0	-0.792×10^{5}	298-2000
SO_2	5.699	0.801×10^{-3}	0	-1.015×10^{5}	298-2000
O_2	3.639	0.506×10^{-3}	0	-0.227×10^{5}	298-2000
N_2	3.280	0.593×10^{-3}	0	$+0.040 \times 10^{5}$	298-2000

Table 10: Mean Heat Capacities of Flue Gas Components

Components	$(C_P)_H$ J/mole.K	$(C_P)_S$ J/mole.K
CO_2	45.6924	44.7424
CO	30.3971	30.1921
NO_2	43.7449	42.9549
SO_2	47.1563	46.3572
O_2	31.6385	31.3632
N_2	30.0178	29.8672

Each individual heat capacity is multiplied by the number of moles of that species in the flue gas and the products are summarized over all species.

$$(C_p)_H{}^{total} = 1137.1408 JK^{-1}$$

$$(C_p)_S^{\text{total}} = 1128.615 JK^{-1}$$

Also

$$\Delta H_d = (C_p)_H^{\text{total}}(T - T_o) = 540141.88 J$$

$$\Delta S_d = (C_p)_S^{\text{total}} \ln\left(\frac{T}{T_o}\right) = 1075.4233 JK^{-1}$$

For the total process the total enthalpy and entropy can be calculated as.

$$\Delta H = \sum \Delta H_i = -227.54212 KJ$$

$$\Delta S = \sum \Delta S_i = -1.2375 KJK^{-1}$$

The steam flow rate is reported to be 500 Kg/sec. in power plant.

$$(500)(3657.0 - 1213.7) + n^o{}_{\text{Rice Husk}}(-227.54212) = 0$$

$$n^o{}_{\text{Rice Husk}} = 5368.896097 \text{ molesec}^{-1}$$

Now ideal work of the whole steam power plant can be calculated as.

$$W_{\text{ideal}} = n^o{}_{\text{Rice Husk}}(\Delta H - T_o \Delta S) = 3202.561259 \times 10^3 \text{ KW}$$

In order to calculate the entropy generation and work lost in the furnace/boiler, turbine, condenser and pump following relationships are used.

$$\Delta(Sm)_{fs} - \sum_j \frac{Q_j}{T_{\partial_j}} = S_G \geq 0$$

$$W_{\text{lost}} = T_\partial S_G$$

The entropy generation and work lost in the each unit of steam power plant is calculated and results are summarized in the **Table 11:** as follows.

Table 11: Entropy Generation and Work Lost Analysis

Equipment	Entropy Generation (KWK^{-1})	Work Lost (KW)
Furnace/Boiler	3487.123	1039.685×10^3
Turbine	232.16	69.218×10^3
Condenser	96.80	28.861×10^3
Pump	499.86	149.033×10^3

A work analysis is carried out in accordance with the equation. The percentage of Ideal work with respect to the individual component of the power plant is summarized in **Table 12**: given below as follows.

$$W_{\text{Ideal}} = W_s + \sum W_{\text{Lost}}$$

Table 12: Percentage of Ideal Work of Individual Power Plant Component

Equipment	Work Lost (KW)	Percentage of Ideal Work (%)
Furnace/Boiler	1039.685×10^3	32.4641
Turbine	69.218×10^3	2.1613
Condenser	28.861×10^3	0.9011
Pump	149.033×10^3	4.6535
Work Lost (Total)	1919.764×10^3	59.8917 **(Efficiency)**
Ideal Work	3202.561×10^3	99.997

Conclusion

It has been concluded that the entropy generation and work lost is highest in Furnace/Boiler that is 3487.12352 KWK^{-1} and 1039.685×10^3 respectively. The work lost in Furnace/Boiler is about 32.4641% while the overall efficiency of the power plant is 59.8917%. From this research it has been also concluded that combustion, as itself entropy generation process the furnace/boiler accounts for maximum work and energy lost. By installing updated thermostat, insulated jacket around the furnace also improving the furnace inspection throughout the year can reduced the energy and work lost significantly.

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