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Efficiency Study of 500 MW PF Boiler and Its Environmental Impact Assessment.

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ABSTRACT

The performance analyzes of the 500 MW PF boiler is presented in this research paper. The performance analyzes of the boiler is carried out as per heat loss method, based on G.C.V of coal (BS EN12952-15:2003). The carbon content, moisture content, volatile matter content and ash content of the coal is analyzed and its effect on the efficiency of the boiler has been studied. The heat balance sheet is prepared to identify the various losses in the boiler and it is observed that heat loss due to dry flue gas contributes for major loss in the boiler. The various parameters which affects the performance of boiler is studied and found that GCV of coal, carbon content of coal and excess air supplied to furnace have significant impact on the efficiency of the boiler. The study is also extended to analyze the impacts of efficiency and specific coal consumption of boiler on emission intensity of various greenhouse gases into the atmosphere and found that deterioration of the efficiency of boiler increases the emission intensity of CO_2. It is found that 1% fall in efficiency of boiler increases the specific coal consumption by 39.07% and CO_2 emission by 40.32%. The outcomes of the study lay the basis to understand the importance of proper maintenance of the boiler and other auxiliary equipment in the power plant and its effect on conservation of fossil fuels and environmental preservation.

Keywords: GCV, Emission intensity, Excess air, Heat balance sheet

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INTRODUCTION

Energy has been universally recognized as one of the most important inputs for economic growth and human development. Coal powered thermal power plant plays a crucial role in facing the energy demand of the nation. Widely PF boilers are used in conventional thermal power stations with the exception of newly constructed TPS with advanced technology boilers, i.e. CFBC, AFBC, and PFBC. So it is very crucial to maintain the boilers to its maximum performance levels. Deterioration of boiler performance will result in failure of the steam generator to produce the required amount of steam to run Turbine from given input of fuel and which will consequently increase the specific fuel consumption and emission intensity. Increase in specific fuel consumption will result in fast depletion of non-renewable energy resources i.e. coal. This study is intended to analyze the major losses involved in the boiler and various factors responsible for it and to study the relation between the inefficiency in boiler and emission intensity of various greenhouse gases.

S. C. Kaushik et al. [1], They have performed energy and exergy analyzes of coal fired thermal power plants and theoretically compared the performance of the respective thermal power stations. Hasan HuseyinErdem et al. [2], They have analyzed the performance of 9 thermal power stations under the Turkish government. The analyzes have been carried out using energy and exergy method. All the thermal power plants considered are of conventional reheat type fed by low quality steam. BrundabanPatro et al. [3],Have studied the boiler consisting of both fire tubes and water tubes. The low quality coal and rice husk is used as the fuel. The heat balance sheet is prepared to identify the major loss in the boiler. Yong Li et al. [4], Have studied the thermal power plants based on the second law of thermodynamics in order to identify the weak links in electricity production and energy losses associated with it. P. Regulagadda et al.[5], Have thermodynamically analyzed the performance of 32 MW coal fired thermal power plants. Hasan HuseyinErdem et al.[6], Have performed the analysis of 500 MW steam turbine cycle form exergetic viewpoint under the design and off design condition. They found that the actual performance degradation is reflected in the exergetic analysis rather than the energetic analysis. Goran D. Vuckovic et al.[7],Have studied the industrial power plant with 33 components and 70 different streams using the first law and second law of thermodynamics in order to find the maximum energy destruction in the system. NurdilEskin et al. [8], Haveanalyzed the pilot plant of capacity 7.7 MW using first and second law thermodynamics. S. K. Som, et al. [9],Has reviewed the studies on thermodynamic irreversibilities and exergy analyzes of combustion of gases, liquid and solid fuels.

The Objectives and Scope of Work

a) To study the performance of boiler and various losses involved in it.
b) To study the quality parameters of coal.
c) To study the relation between the quality of coal, boiler efficiency and emissions.

Technical Specifications

a) Fuel Burning Equipment
Type : Tilting Tangential
Make : BHEL
Capacity : 75.6 x 10^6 kcal/hr
Furnace : Balanced Draft furnace with fusion welded water walls.

b) Steam generator
Type : Controlled circulation with Rifled tubing, Radiant Reheat, Dry bottom.
Super Heater : Stage 1- SA231, 207.3 Kg/cm^2, 455^{o}C (Max. operating pressure & Temp.).
Stage 2-SA231, 202.8 Kg/cm^2, 520^{o}C (Max. operating pressure & Temp.).
Stage 3-SA231, 197.4 Kg/cm^2, 598^{o}C (Max. operating pressure & Temp.).
Reheater : SA 231 T11, 53.4 Kg/cm^2, 584^{o}C (Max. operating pressure & Temp.).
Air Preheater : Regenerative Trisector APH.
Drum : SA299, 195 kg/cm^2 (operating pressure), 368^{o}C (operating temperature).
Economizer : SA 210 Gr A1, Seamless plain tube construction, non-steaming, inline tube type. 216 kg/cm^2 (operating pressure), 322^{o}C (operating temperature).

METHODOLOGY

Efficiency test will be done as per BS EN 12952-15:2003 Heat loss method (Based on GCV of coal).No heat credit will be considered. Loss due to unburnt carbon is considered as 1.5% or actual, whichever is higher. Efficiency test is done at 100% TMCR (500 MW).Heat loss due to radiation will be measured based on BS EN-12952-15:2003 code. The flue gas temperature at AH outlet at 100% TMCR -125^{0}C (minimum). The efficiency test will consist of basically one run of 4 hours duration. Test is conducted after the optimization of the boiler. Prior to the stabilization period, unit operation will be adjusted to required parameters. Four hours prior to actual commencement of test, all wall blowers and soot blowers will be operated to keep the surface clean. Test shall commence after allowing 4 hours of stabilization period after soot blowing operation. For maintaining 20 % excess air, O_2 will be maintained at 3.5% at economizer outlet based on multi-grid local measurement. Gas dampers at air heater outlet will be modulated to equalize gas temperature. During test all blow downs will be kept closed and no oil support is provided.

Table 1: Boiler Operational Parameters

S. No.	Parameters	Unit	DV	T1	T2	T3	T4	T5
1	Unit load	MW	500	462.23	486.77	503.37	500.4	501.85
2	Feed water flow	T/hr	1457	1463.5	1440	1568.5	1561	1560
3	Main steam flow	T/hr	1457	1380.9	1400.7	1485.2	1506	1512.3
4	Total air flow	T/hr	1839	1655.9	1619.4	1756.2	1677	1716.0
5	Mills in service	Nos.	6	6	6	6	6	6
6	Coal flow t/hr	L_{flow}	304	241.11	250.89	300.09	263.8	284.28
7	% Unburnt carbon	C	1.5	2.5	2.04	2.02	3.00	2.50
8	%of bottom ash	Pba	20	20	20	20	20	20
9	% of fly ash	Pfa	80	80	80	80	80	80
10	Ambient temp ^{0}c	T_a	27	34	32.5	32	32	32.50

The Computation of Losses

The proximate analysis value has to be converted to ultimate analysis by using below mentioned formulae in order to

$$\%C = 0.97C + 0.7(VM + 0.1A) - M(0.6 - 0.01M) \quad (1.1)$$

$$\%H_2 = 0.036C + 0.086(VM - 0.1A) - 0.0035 \times 2 \times M(1 - 0.02M) \quad (1.2)$$

$$\%N_2 = 2.10 - 0.20VM \quad (1.3)$$

$$\%O_2 = 100 - (M + A + CA + H_2 + N_2 + S) \quad (1.4)$$

In order to improve the efficiency of the combustion process in the boiler, the stoichiometric ratio of coal and air has to be supplied. But in practical operation of the boiler some excess air will be supplied for safety and maintenance needs. This excess air will have negative effects on the efficiency of the boiler. From boiler operation standards, excess air upto 15% is acceptable, but it is clear from the above table that excess air supplied is above the acceptable range which will significantly affect the performance of boiler resulting in emission of more greenhouse gases and will also increase the specific fuel consumption.

$$M_{CO2} = \left(\frac{C}{100}\right) \times \left(\frac{44}{12}\right) \quad (1.5)$$

$$M_{SO2} = \left(\frac{S}{100}\right) \times \left(\frac{64}{32}\right) \quad (1.6)$$

$$M_{N2} = AAR \times 0.77 \quad (1.7)$$

The above relations are used to calculate the amount of greenhouse gases produced during the combustion of coal based on the percentage of fixed carbon, sulphur, nitrogen content of the coal.

There are many types of losses involved in the boiler but stack loss or dry flue gas loss is the major loss involved in the boiler. It is caused by the thermal energy carried away by the flue gas leaving the boiler. The next major loss is caused by the hydrogen in the fuel. Hydrogen molecules in the coal react with the O_2 molecule in the combustion air and form water molecules which will absorb latent heat gets vaporized resulting in the inefficiency of the steam generator. And moisture in the coal and air will also absorb some portion of thermal energy from the furnace and gets converted into superheated steam resulting in reduced efficiency of the boiler.

The below relation is used to compute the overall efficiency of the boiler,

$$\eta = (100- (HL_{DFG}+ HL_{H2}+HL_{H2O\,(fuel)} +HL_{H2O\,(air)} + HL_{UA}+ HL_{UA}) \qquad (1.8)$$

As per second law of thermodynamics, the heat supplied to the boiler cannot be fully converted into work, but the losses in the boiler can minimized to a major extent. From the study it is found that boiler efficiency will get enhanced by 0.1-0.2 % for every 1% fall in moisture content of coal. And boiler efficiency will get improved by 2% for every 1% fall in hydrogen content of coal.

Table 2: Fuel Analysis

S.No.	Parameters	DV	T1	T2	T3	T4	T5
1	Carbon (%)	36.70	62.97	43.60	43.33	41.84	47.32
2	Hydrogen (%)	3.30	4.15	2.40	2.33	2.22	2.64
3	Sulphur (%)	0.30	0.50	0.50	0.45	0.45	0.50
4	Nitrogen (%)	0.83	1.43	1.65	1.67	1.69	1.65
5	Oxygen (%)	8.52	9.20	6.83	6.89	6.10	6.13

Table 3: Percentages of combustion air supplied

S. No.	Parameters	DV	T1	T2	T3	T4	T5
1	T.A.R	5.03	8.37	5.62	5.56	5.38	6.16
2	E.A.	20.55	23.17	20.17	22.09	22.53	18.71
3	A.M.A.S.	6.07	10.31	6.75	6.79	6.54	7.31

Table 4: Flue gas analysis

S.No	Parameters	Unit	DV	T1	T2	T3	T4	T5
1	M_{CO2}	%	1.33	2.31	1.60	1.59	1.53	1.73
2	M_{SO2}	%	0.01	0.01	0.01	0.01	0.01	0.01
3	M_{N2}	%	4.67	7.94	5.20	5.23	5.04	5.63
4	M_{O2}	%	0.24	0.45	0.26	0.28	0.28	0.26
5	M_{DFG}	%	6.27	19.10	12.53	7.12	7.12	7.665
6	% Unburnt Carbon	%	0.0054	0.0032	0.0067	0.0065	0.0110	0.0079

Table 5: Heat Losses in Boiler

S.No.	Parameters	DV	T1	T2	T3	T4	T5
1	HL_{DFG}	4.207	4.830	4.382	4.365	4.193	4.204
2	HL_{H2}	4.862	4.490	3.470	3.384	3.370	3.612
3	HL_{H2O}(fuel)	2.308	1.113	2.031	2.107	2.081	1.706
4	HL_{H2O}(air)	0.132	0.178	0.166	0.164	0.158	0.159
5	HL_{UA}	1.5	0.495	1.395	1.392	2.412	1.566
6	Efficiency	85.90	87.81	87.47	87.50	86.7	87.6

Table 6: CO_2 Emission

S.No	Efficiency (%)	G.C.V (Kcal/kg)	Coal Consumption (T/Annum)	CO_2 Emission (T/Annum)
1	85.90	3700	2941958.4	2956668.192
2	86.7	3721.8	2913838.8	2928407.994
3	87.47	3926.61	2733120.0	2746785.65
4	87.81	5228.2	2094134.616	2095181.6

The Computation of Co_2 Emission

The power plant has significant impact on the environment during both construction and operation of the plant. During the regular operation of the plant large quantities of the greenhouse gases such as SO_2, CO_2& CO etc. are released into the environment which will disrupt the entire ecosystem. The uncontrolled emissions of the greenhouse gases will severely affect the environmental ecosystem. In this study emission of the greenhouse gases is studied quantitatively and the results are tabulated below.

As per Environmental & forests central pollution control board, the limit for NO_x emission for existing thermal power plants are 150 ppm at 15% excess oxygen. As per the central board So_x emission must be 80µg/m^3 (Industrial areas) and 60µg/m^3 (residential areas). The limits for SPM are 360µg/m^3 (Industrial areas) and 140µg/m^3 (residential areas). The emission levels will increase based on the plant age factor and also depends on the O&M of the plant.

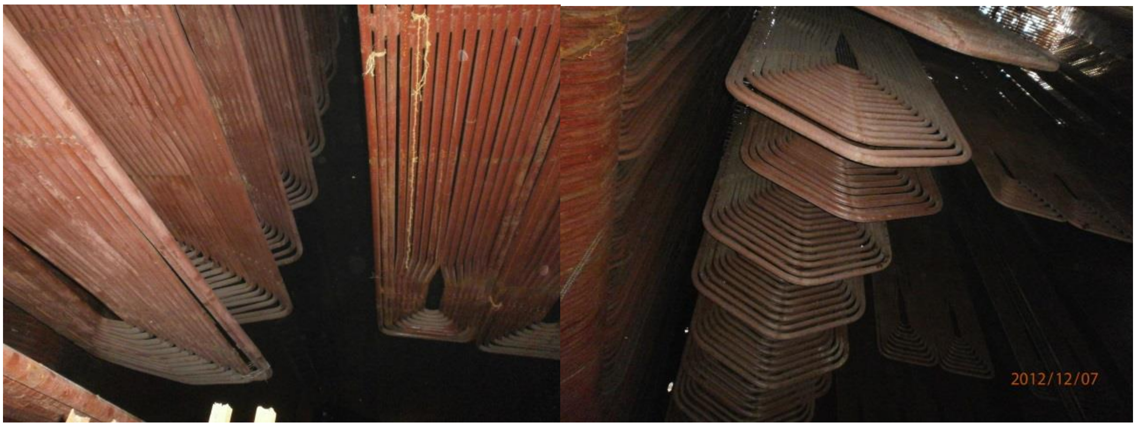

Figure 1: Inner view of the PF boiler (Super heater coils)

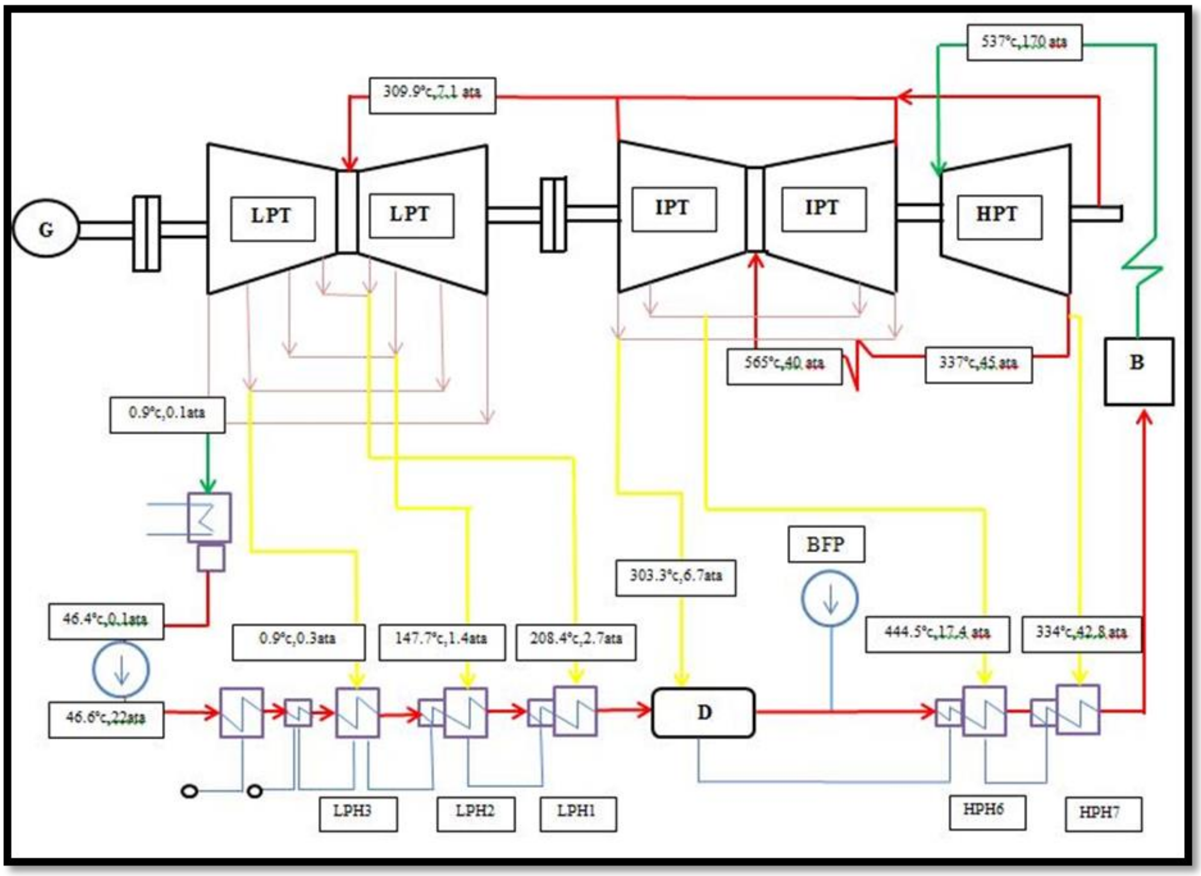

Figure 2: Flow Diagram of 2x500 MW Thermal Power Plant

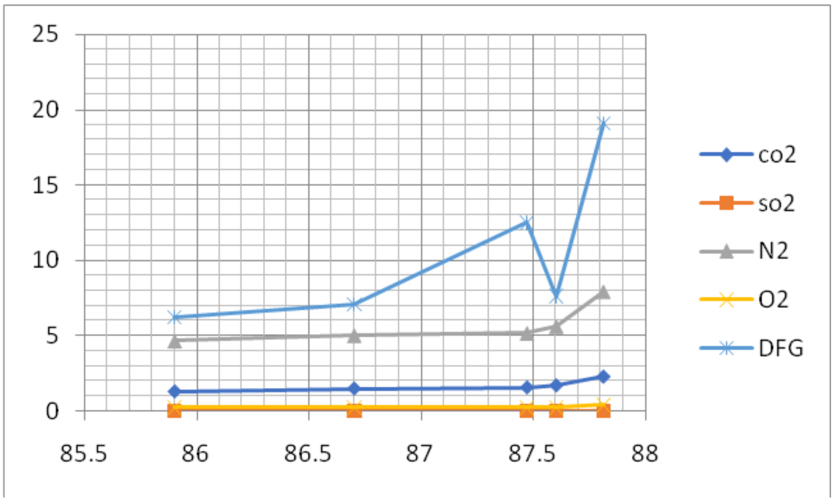

Figure 3: Efficiency vs. GHG

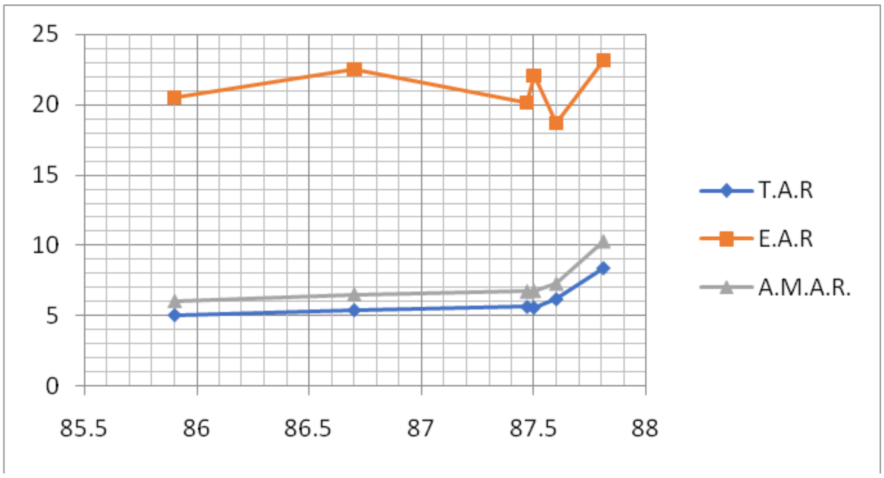

Figure 4: Efficiency vs. Air Requirement

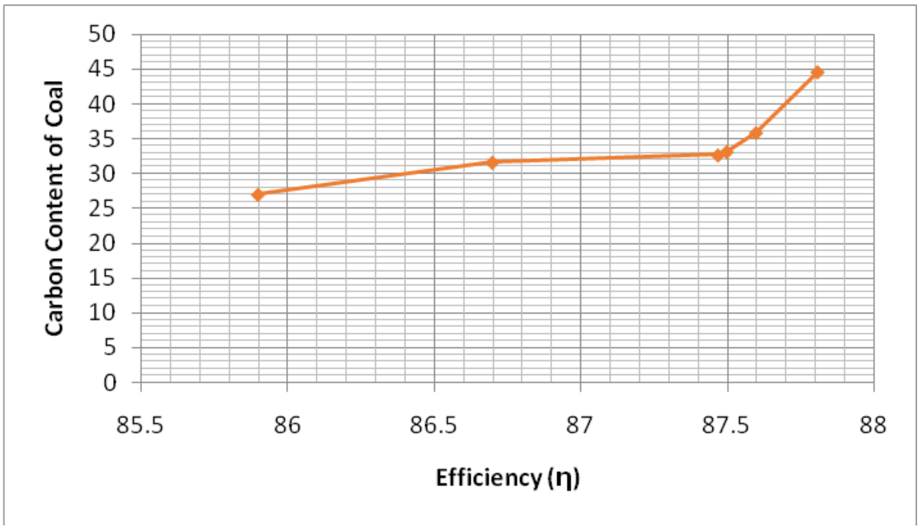

Figure 5: Efficiency vs. Carbon content

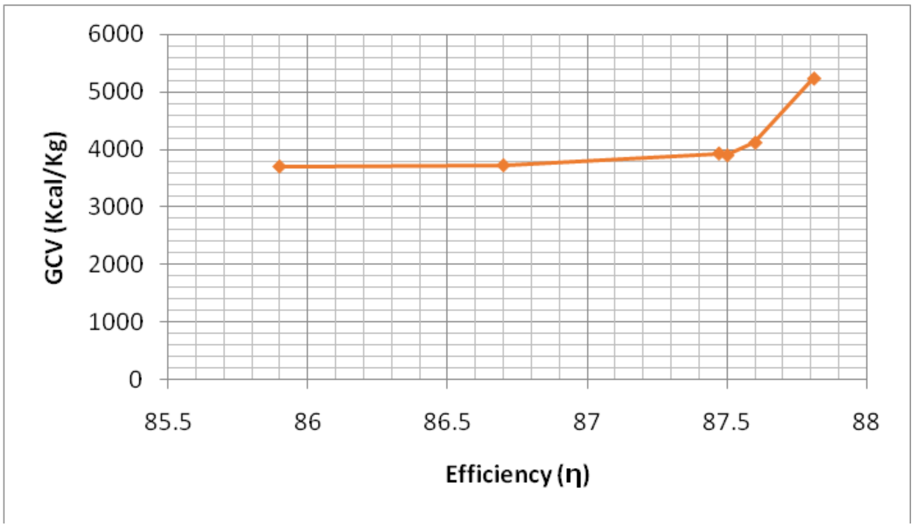

Figure 6: Efficiency vs. GCV

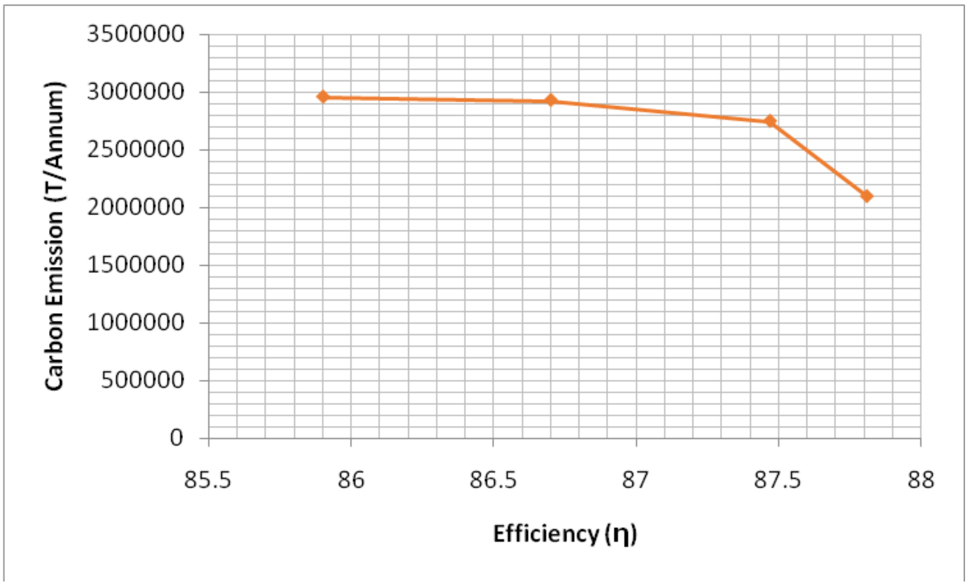

Figure 7: Efficiency vs. Carbon Emission

INFERENCES AND DISCUSSIONS

The efficiency of the thermal power plants plays significant role in depletion of fossil fuels and thermal power plants are the major contributor of greenhouse gases to environment. The steam generator or boiler is the heart of the thermal power plants which will convert the chemical energy of fuel to thermal energy and this conversion cannot be 100% efficient since there are many unavoidable losses in the boiler which are analyzed using the heat balance sheet. And found that loss due to dry flue gas and H_2 in fuel is higher and it is found that 1% decrease in efficiency of the boiler will result in increase in CO_2 emission by approx. 34419.88582 T/Annum. And it will increase the fuel consumption by approx. 34248.64 T/Annum. From this study it is evident that efficiency of the PF boiler is directly proportional to GCV (Gross calorific value) of the coal used irrespective of all other factor concerned in the efficiency of the boiler. And GCV of the Indian coal is lower so it can be blended with the imported coal which results in higher efficiency of the steam generator. Next factor of the fuel which has direct influence on the efficiency of the boiler is the carbon content of fuel. It can be observed that higher the carbon content of fuel, higher is the efficiency of the boiler. Excess air supplied is the major factor which has the direct influence on the complete combustion of fuel and consequently decreases in percentage of unburnt carbon in ash. Hence excess air optimization is the key factor responsible for efficient operation of the boiler. It can be inferred that reduction in efficiency of boiler will result in increase in emission of CO_2, which is the GHG which is major factor responsible for global warming. For 500 MW TPS 1% reduction in efficiency will increase the heat rate which conquently increases the fuel consumption in turn increases the CO_2 emission by approx. 34248.64 T/annum. The total power production through thermal power plants in India is 188967.88 MW so it can be understood that even 1% reduction in efficiency of all boilers in TPS will result increase in CO_2 emission by enormous amount.

CONCLUSIONS

The emissions from the thermal power plants have the major contribution to anthropogenic pollution. But thermal power plants play the major role in facing the energy demand of the nation so proper technologies has to be implemented to minimize the emissions from the plant and to conserve the fossil fuels for the future generation. The latest technologies include on-line data base management of emission levels of the pollutants to ensure that emissions from the plant do not exceed the range prescribed by the government. The environmental parameters must be monitored during the operation of the plant and proper techniques to reduce the emissions such carbon sequestration must be implemented. In order to improve the combustion efficiency excess air supplied must be optimized which will reduce the emissions drastically. The quality of the coal used has the huge impact on the boiler performance so good quality of coal must be used. Since the moisture and volatile matter content of the Indian coal is lower it can be blended with the imported coal which will results in improved quality of the coal.

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