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Performance Enhancement Of An Industrial Fire Tube Boiler

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Abstract

An Industrial boiler is considered as highly energy intensive equipment. The primary objective of this study is to identify and quantify the potential losses of different energy sections of the fire tube boiler and its overall performance. Several energy saving measures such as combustion optimization, excess air control, control of flue gases temperature and effect of excessive or uncontrolled steam blowdown optimization, on the overall performance of boiler are also applied. Energy as a result of energy saving measure has been determined as well. In present study, some main causes of energy wastages are summed up, by using an energy auditing. From the results of energy audit, the boiler's thermal energy efficiency and combustion efficiency are found to be 70.09% and 75.70% respectively. The boiler overall energy efficiency from 70.09% to 73.27%. It was also observed that these losses can be reduced by controlling stack temperature, excess air and optimized blowdown. There covered energy can be utilized to preheat the combustion air and feed water. Economic evaluation of energy saving measures in annual fuel resulted savings of 6.3 Million PKRs without any investment but only improving working methodologies. As a result of these efforts, the savings in terms of cost has also been determined.

***Keywords**: Steam Boiler, Steam, Boiler Efficiency, Stack Gas, Blowdown*

1. Introduction:

The success and well being of the world is associated with the growth in energy sector. Since world is facing severe energy challenges especially the new energy sectors must be environmentally feasible for fulfilling the energy requirements. In 2040, the residential and industrial growth will demand higher energy requirements; therefore the world must fulfill these requirements by increasing the efficient use of energy and should focus on lower carbon fuels.

In developing countries, energy requirements will grow close to 60 percent as five-sixths of the world's population strives to improve their living values.

Pakistan is currently facing the vital energy crises both in domestic and industrial sector. The increasing demand needs optimization at demand side. One possible way is to improve the existing units for more efficiency i.e. by introducing new technologies and reduction of losses. Pakistan is developing country and installation of new energy units is very difficult as it requires massive investment and time. Furthermore, improving the already existing energy units by replacing with new advanced technologies is also very hard to achieve. However, Pakistan could reduce the losses incurred during the generation and transportation of energy as it requires relatively less investment and time.

Steam is an integrated part of process industry and a critical source in today's industrial world. The system in which steam is generated is called a boiler or a steam generator. Steam boilers are closed

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vessels which are usually used to produce steam from water by combustion fossil(Rajput 2010). Steam boiler is made up of two major parts, i.e. the combustion chamber, which provides heat by the combustion of fuel, and the heat exchanger which transforms water into steam through heat exchange in the medium.

Boiler types comprises of fire tube, water tube, modular, coil tube and cast iron (Kakaç 1991). Fire-tube boilers are safer to use, require less expertise, and operate under lower pressures than water-tube boilers. Thus they are more suitable for small scale applications (Saidur, Ahamed et al. 2010; De Santi and Valentino 2011). Water tube boilers, on the other hand, have a higher rate of steam production and are easier to construct and transport.

Some recent papers have been published regarding with other aspects of fire-tube boilers including the options of their performance enhancement and improvement in their energy efficiency,(Aydin and Boke 2010; Behbahani-Nia, Bagheri et al. 2010).Efforts have been made to improve and enhance the performance of fire tube boiler. Since in Pakistan boiler's still finds lots of application in industry, so it can save around 10-30% of thermal energy if boilers are operated more efficiently. The optimization or improvement in operation of boilers could leads to reduction in fuel consumption and improvement in steam and generation capacity.

2. Process Description:

In the present research work the procedure adopted was based on the identification of losses incurred during the operation of an industrial fire tube boiler and the evaluation of these losses and its remedies. Boiler's performance was evaluated by the use of the Flue gas analyzer, TDS meter and Thermometers.

Energy required in the boiler and energy cost can be found by using equations 1 and 2 as:

$$\textbf{Energy required} = \int (\boldsymbol{Load}) * \frac{\mathbf{1}}{\boldsymbol{Efficiency}} \, .\boldsymbol{dt} \rightarrow \mathbf{(1)}$$

$$\textbf{Energy cost} = \int \textbf{(Load)} * \frac{\mathbf{1}}{\textbf{Efficiency}} * \textbf{(Fuel cost)}.\textbf{dt} \rightarrow \textbf{(2)}$$

It is not easy to get the energy requirements and cost from above equations, as efficiency depends upon the load, weather conditions and time. However, the cost of fuel could be a function of ground realities of politics and international market price of fuel fluctuations. Decreasing system load or system efficiency, both can make the process more economical and energy efficient, while the inverse is always avoided,[9].

The boiler operating parameters are summarized in Table 1.

Table 1: Properties of the Fire Tube Boiler

Parameters	Units	Values
Design capacity	Ton/hr	18
Operating capacity	Ton/hr	13
Boiler Type	-	Packaged type, Three Pass, Fire Tube
Heating area	m^2	725
Draft type	-	FD
Design pressure	Bar	15
Operating pressure	Bar	13
Burner type	-	Dual (Natural Gas & Diesel)

3. Performance Analysis of the Boiler

Since there is a direct relation between energy conservation and boiler performance and the performance of the boiler which is highly dependent on time [10]. An efficient operation of boiler requires less amount of fuel in input and can produce maximum energy at output, which is an indication of an efficient energy conservation system. The efficiency of the boiler [11] was found by carrying out performance tests at regular intervals using equations 3 and 4 mentioned below:

$$\textit{Boiler efficiency}= \frac{\textit{Heat in steam output(kCal)}}{\textit{Heat in fuel input (kCal)}} * 100 \quad (3)$$

$$\text{Boiler efficiency}= \frac{\textit{Quantity of steamg eneration}}{\textit{Quantity of fuel consumption}} * 100 \quad (4)$$

It is the input-output method which comprises of chemical energy gained from the combination of the boiler fuel. The boiler efficiency was calculated with the help of recorded data, i.e. steam generated per hour (kg/hr), fuel used per hour (kg/hr), operating condition (Temperature and pressure), boiler feed water temperature (oC) and fuel heating value GHV (kCal/kg of fuel). The primary objective of this activity was to evaluate the actual performance of the fire tube boiler and to draw a comparison between its design values in order to get the effect of time to be evaluated so that the required maintenance can be applied. The Boiler was tested according to American Society of mechanical engineers (ASME) power test code 4.1 (PTC-4-1) which is specified for steam generating units

4. Results & Discussion:

The major contribution factors in the thermal evaluation of subjected three pass, fire tube boiler stack temperature and blowdown.

4.1 Stack Temperature & Excess Oxygen in Flue Gas

Combustion efficiency was improved by 3% by decreasing the stack temperature from 319°C to 230°C. This improvement in the value of combustion efficiency can be achieved by adjusting flow drift velocity, which can be obtained by installing pre-heaters or economizers (i.e. utilization of extra heat) as shown in Fig.-1. In addition, due to the reduction in the flue gas temperature, the excess air quantity in combustion systems can also be optimized. When the fuel gas fed to the boiler at 170°C, The percentage of oxygen stack reduced to 2.6% (the maximum allowable reduction flue gas analysis can seen from Table 3). Above this value the quantity of un-burned carbon in the stack was found to be increased, as seen in Table 2. The reduction temperature of flue gases, 2.7 million PRS can be saved annually

Table 2: "Improved Efficiency and potential/ potential Cost Saving"

Parameters	Units	Actual Value	Improved Value
Mass flow rate of steam	Ton/hr	13	13
Existing Stack Temperature	°C	319	319
Controlled Stack Temperature	°C	170	230
Oxygen in Stack	%	3.50	3.50
Excess Oxygen Optimization	%	2.20	2.60
Existing Thermal Efficiency	%	75.50	75.70
Improved Thermal Efficiency	%	83.15	79.82
Load	Ton/hr	113,880	113,880
Cost	Rs/Ton	1,215	1,215
Existing Operating Cost	Rs/Yr	138,364,200	138,364,200
Saving in Yr	Rs	5,019,356	2,743,915

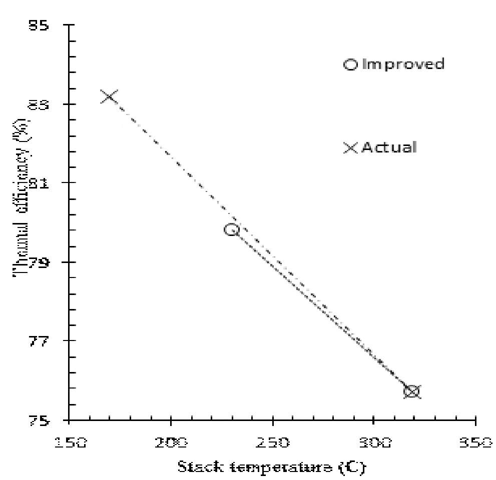

Figure-1: Effect of reduction in stack temperature on Thermal Efficiency

Table-3: Flue gas analysis results

Parameters	Units	Actual Values	Improved Values	NEQs
Operating Pressure	Bar	13	13	-
Ambient Temperature	°C	37	37	-
Exhaust Gas	°C	319	230	-
Temperature				
CO_2	%	10.76	11.92	-
O_2	%	3.50	2.60	-
H_2S	mg/Nm^3	ND	ND	-
CO	mg/Nm^3	716	548	800
SO_2	mg/Nm^3	0	0	-
NO^2	mg/Nm^3	5	4	-
NO	mg/Nm^3	106	131	-
NO_x	mg/Nm^3	111	108	400
Combustion Efficiency	%	75.70	79.82	-

By obtaining both of the above optimizations in our thermal system, we can achieve the following potential saving shown in Figure 2;

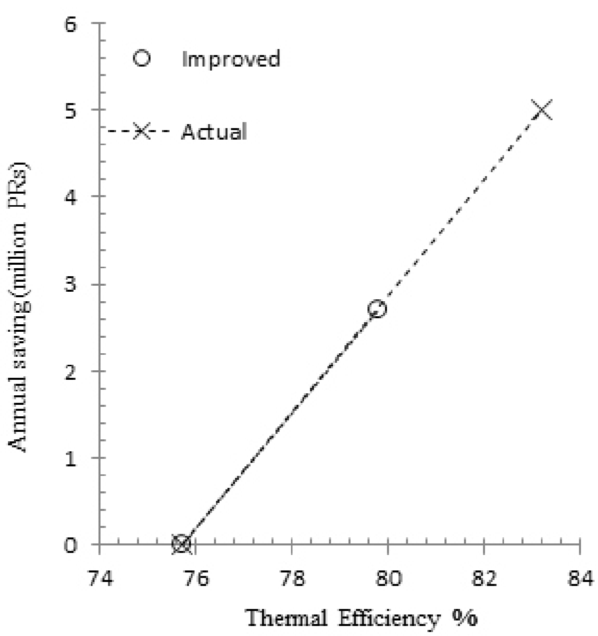

Figure 2: *Improved Efficiency and Potential/ Improved Annual Cost Saving*

More ever, the annual savings as a function of thermal efficiency has been depicted in Figure 2. Due to the decrease in flue gas temperature the annual savings can be increased.

As the blowdown process involves the continuous removal of water from a boiler to remove accumulated dissolved solids which in the return prevents the scale formation. Scale, having low thermal conductivity, causes fuel wastage typically up to 5% in fire tube boilers. As a rule of thumb, one millimeter of scale build-up can increase fuel consumption by 2%[12].Hence the blowdown wastes energy because the blowdown water is at boiler working pressure and temperature at which the steam is produced. Higher blowdown quantity results in the loss of fuel and eventually the boiler efficiency. Blowdown losses also include the losses through the additional cost for makeup water supplied and its softening costs [13]. In current boiler system, the efficiency was enhanced by reduction in blowdown, i.e. by decreasing the blowdown time, increasing the limits of blowdown TDS and adopting proper blowdown sample collection method.

Table 4: Blowdown Calculations

Parameters	Units	Existing Values	Improved Values against the Actual Values
Time	hr	0.25	0.20
Blowdown	per	3	3
Frequency	day		
Feed water	ppm	50-100	50-100
TDS			
Blowdown TDS	ppm	2500	3500
Blowdown Loss	%	3.80	2.20

The proposed results were determined and represented along with improved values of the blowdown system. (See table 5).

Table 5: Proposed and Improved Savings in Blowdown System

Parameters	Units	Actual Values	Improved Values
Mass flow rate of steam	Ton/hr	11.37	11.37
Blowdown	%	3.80	3.80
Steam waste in blowdown steam	Ton/day	10.37	10.37
Proposed blowdown	%	1	2.20
Proposed steam waste in blowdown	Ton/day	2.73	6
Steam saving	Ton/day	7.64	4.37
Amount of gas required for 1 ton steam	Nm3/Ton	73.26	73.26
1 MMBTU is equivalent to	Nm3	30.14	30.14
MMBTU for 1 ton steam	MMBTU	2.43	2.43
MMBTU saved by improving blowdown	MMBTU	18.56	10.62
Cost of MMBTU	PKR	500	500
Financial saving	Rs/day	9,284.20	5,310
Financial saving	Rs/yr	3,388,731	1,938,150

Due to the reduction in the blowdown the annual savings and reduction in energy losses are shown in Fig.-3. It can be observed from the table 6 that as the blowdown was reduced to 2.2%, the thermal and overall efficiencies increased up to 73.27% and 79.8% respectively. While, on the other hand, stack gas temperature also reduced to 230 C, which leads to less thermal pollution. In addition, the cumulative effect of the improvement in overall and thermal efficiency can be observed by performing the cost analysis. It can be deduced from the table 7 that as a result of the decrease in the amount of blowdown will augment the financial savings (composed of fuel and energy saving) significantly, i.e. up to 6.2 million PRS.

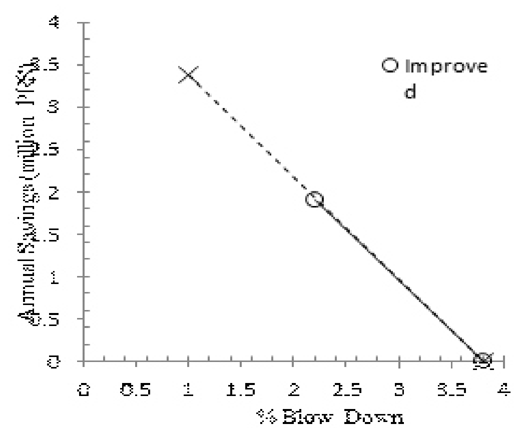

Figure 3: Blowdown reduction and Potential/ Improved Annual Cost Saving

Summarizing the results, we need to adopt following changes in our system, shown Table 6:

Table 6: Proposed improvements

Parameters	Units	Present	Proposed	Improved
Overall Efficiency	%	70.00	75.00	73.27
Combustion Efficiency	%	75.70	83.20	79.80
Stack Gas Temperature	°C	319.00	170.00	230.00
O2	%	3.50	2.20	2.60
Excess Air	%	11.70	10.50	10.90
Blowdown	%	3.80	1.00	2.20
Blowdown limit	TDS	2500	3500	3500

By these changes, following benefits in terms of energy saving and financial savings are obtained (Table 7):

Table 7: Financial Saving Opportunities

Current Scenario		Modified Scenario		Fuel Saving	Energy Saving	Financial Saving
Efficiency	Fuel	Efficiency	Fuel	m^3/hr	MMBTU/hr	Rs./year
%	m^3/hr	%	m^3/hr			
70.09	883.00	75.00	825.18	57.82	1.91	8408087
Actual Improvement						
73.71		839.96		43.04	1.12	6258805

5. Conclusions:

After detailed study of system and then implementing the potential proposed saving of fire tube industrial boiler for efficiency enhancement, following conclusions has been prepared:

Calculations show that by improving thermal efficiency, not only problems of high stack temperature and excess air has been managed, but also a saving of about 5 Million PKR was achieved on a year in terms of fuel saving

Controlling excess air results in energy efficiency in terms of fuel saving, which is equal to about 3 million PKR in a year.

By adjusting parameters in blowdown system, we reduced the blowdown percentage by 2.2% which came up with about 2 million PKR savings.

Improving overall efficiency from 70.09% to 73.27%, results with about 6.25 million PKR savings, which is about 4.9% of direct fuel saving.

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