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Investigation of Improvement in Boiler Efficiency through Incorporation of Additional Bank of Tubes in the Economiser for Supercritical Steam Power Cycles

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Abstract:—The major efficiency loss of a boiler is caused by the hot stack gases discharging to the atmosphere which is polluting the atmosphere and on other side Pollution Control Board is forcing the norms of Pollution levels in atmosphere. One of the most cost-effective ways of improving the efficiency of a high pressure steam boiler is to install an economizer on the boiler. Typically, on a high pressure water tube boiler, the efficiency improvement with an economizer is 2 to 4%, depending on firing rate. On a high pressure fire tube boiler, the improvement is 2 to 3.5%, depending on boiler size and firing rate. The economizers are located in the boiler stack close to the stack gas outlet of the boiler. A feedwater line, which serves the boiler, is piped to the unit. No additional feedwater control valves or stack gas dampers are required. Presently in NTPC stage II units there are some bank of tubes in economizer. There was a proposal from management to add another bank of tubes in the economizer so that there will be control of pollutants coming out from boiler, and to find how much feed water temperature raises both from subcritical and Supercritical operating conditions. An investigation is conducted on the effect of performance of the boiler by incorporating the additional bank of tubes in the space below the lower bank of tubes. The main idea is to extract maximum amount of heat from the flue gases and increase the heat pick up rate of the feed water outlet into the boiler. By assuming the additional bank of tubes, various heat transfer calculations are done and the reduction in the flue gas outlet temperature and increase in the feedwater outlet temperature are found out. Finally a comparison of efficiencies of the boiler is made between the existing unit and the unit when additional bank of tubes are assumed both for subcritical and Supercritical operating parameters mode. At last, various pros and cons have been found out by conducting above investigation i.e. by incorporating additional bank of tubes in the economizer.
Keywords:—Ultimate Analysis, Proximate Analysis, Air Preheater (APH), Supercritical Cycle, Economiser

I. INTRODUCTION

Economizers (some times shortened to “eco”)or Feed water Preheater is a steam generator’s penultimate fire side heating surface and at the same time its first heating surface on steam side. Economizers are gas-to-liquid heat exchangers that recover heat from flue gas streams and transfer it to water or another fluid. These units are typically used for boiler feedwater heating and process water heating [1]. Thermal transfer's economizers offer compact designs with finned tubes [2]. Different types of fins can be utilized to coordinate with specific application requirements, primarily relating to fuel type and flue gas characteristics [4, 5]. The function of the economizer in a steam generating unit is to absorb heat from the flue gases and add this as sensible heat to the feed water before the water enters the evaporative circuit of the boiler [3]. Earlier the economizer was introduced to recover the heat available in flue gases that leaves the boiler and provision of this additional heating surface increases the efficiency of steam generation, saving in fuel consumption, thus the name economizer christened [6]. In the modern boilers used for power generation feed water heaters were used to increase the efficiency of the turbine unit and feed water temperature and hence the relative size of the economizer is less than the earlier units [9]. The major efficiency loss of a boiler is caused by the hot stack gases discharging to the atmosphere. One of the most cost-effective ways of improving the efficiency of a high pressure steam boiler is to install an economizer on the boiler [10]. Therefore, an economizer is a heat exchanger, which transfers heat from the stack gases to the incoming feedwater. Typically, on a high pressure water tube boiler, the efficiency improvement with an economizer is 2 to 4%, depending on firing rate [13]. On a high pressure fire tube boiler, the improvement is 2 to 3.5%, depending on boiler size and firing rate. As the temperature difference between two working media is small, economizer needs a very large heat exchange surface. The risk of corrosion from flue gases cooling below their dew point must be avoided [14]. Cold feed water must therefore not be feed to the economizer. The regenerative feed water preheating, this heats the feed water up to the temperature of 200-300 ^{0}C before it enters the economizer and which lets the flue gas cools down to the temperatures of , at most ,above the level determines the fireside outlet temperature of depending on the Terminal Temperature Difference (TTD) of the economizer [16] . If Nitrogen Oxide control is necessary, further requirement for the flue gas temperatures between the economizer and the air preheater may arise (Reuter and Honig 1988). In so called high dust configurations, the catalyst is mounted between the economizer and the air preheater [18]. A catalytic flue gas DENOx reactor needs a reaction temperature of about 350 ^{0}C, which is provided in the location. The relative heat absorptions of the economizer are dependent on pressure as evaporation enthalpies decrease with higher pressures [20].

The Present work is to carry out by providing an additional bank of tubes in the economizer for checking its performance levels and Pollution level controls both for subcritical and supercritical operating mode conditions.

II. LOCATION AND ARRANGEMENT OF ECONOMISER IN THERMAL POWER PLANT

It is usually to locate the economizer, a header of an air heaters and following the primary super heaters or reheaters in the gas stream. Hence it will be generally be contained in the same casing as the primary super heaters are reheaters. Counter flow arrangement is normally selected so that heating surface requirement is kept minimum for the same temperature drop in the flue gases. Economizer coils are designed for horizontal placement which facilitate draining of coil and favors the arrangement in the second pass of the boiler. Water flow is from bottom to top so that steam if any formed during the heat transfer can move along with the water and prevent the lock up steam which will cause overheating and failure of economizer tube.

Economizer tubes are supported in such a manner that sagging, undue deflection and expansion prevention will not occur at any condition of operation. A recirculation line with a stop valve and non return valve may be incorporated to keep circulation in the economizer into the steam drum when there is a fire in the furnace but not feed flow.

Tube elements composing the unit are built up in to banks and these are connected to inlet and outlet headers. Man holes and adequate access and spacing between banks of tubes are provided for inspection and maintenance works. Normally the tube bank arrangement and steam soot blowers provision at appropriate location will facilitate efficient a load cleaning. An ash hopper below the economizer is provided if the flue gas duct is taking a turn from vertical. Therefore, economizers are located in the boiler stack close to the stack gas outlet of the boiler. They may be supported from overhead or from the floor. A feedwater line, which serves the boiler, is piped to the unit. No additional feedwater control valves or stack gas dampers are required. Flue gases from large boilers are typically 232.5 – 343.5°C. Stack Economizers recover some of this heat for pre-heating water. The water is most often used for boiler make-up water or some other need that coincides with boiler operation. Stack Economizers should be considered as an efficiency measure when large amounts of make-up water are used (i.e.: not all condensate is returned to the boiler or large amounts of live steam are used in the process so there is no condensate to return) or there is a simultaneous need for large quantities of hot water for some other use.

The savings potential is based on the existing stack temperature, the volume of make-up water needed, and the hours of operation. Economizers are available in a wide range of sizes, from small coil-like units to very large waste heat recovery boilers.

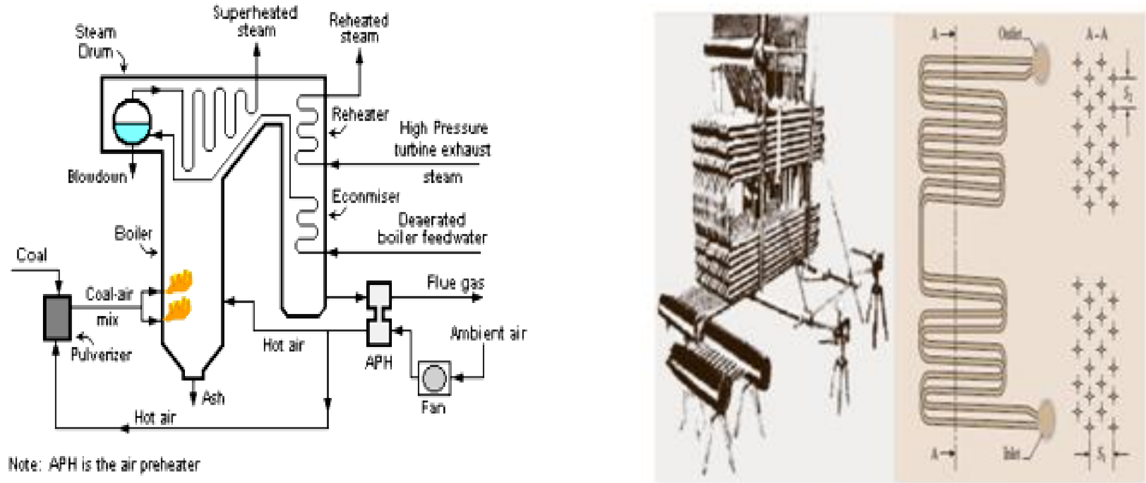
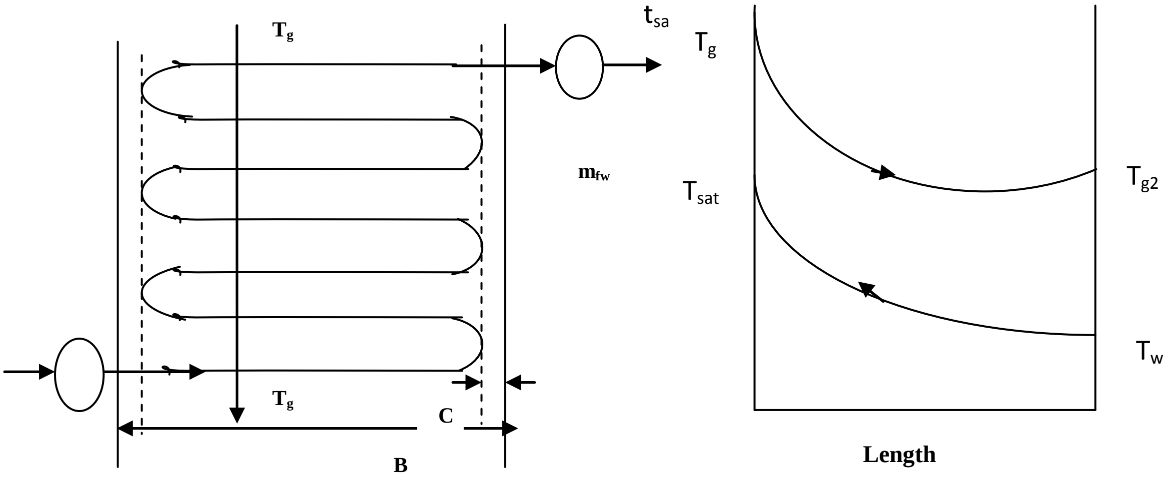


Fig.1 *Schematic layout of Boiler with Economizer location [12, 22]*

III. ARRANGEMENT OF MAIN BOILER

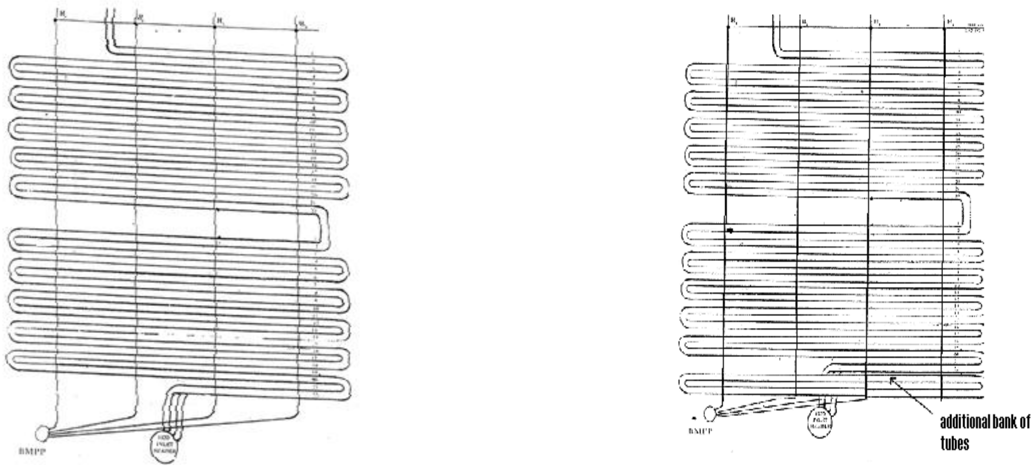
The accessories include the following:-

1. Economizer
2. Boiler drum
3. down comers
4. Water Walls
5. Water Wall Platen (used for low pressure boilers)
6. Primary super heater
7. Platen super heater
8. Final super heater
9. Reheater
10. Burners
11. Ignitor



(a) **(b)**

Fig. 2. *(a)Dimensions of Economiser [10]* *(b) Temperature Profile of Economiser [10]*



.3 (a) Economizer before modification [1] *(b) Economizer after modification [1]*

Table 1: Design Data existing at NTPC Plant [1]

Parameter	**Flue Gas**	**Feed Water**
Out let temperature	368 ^{0}**C**	304 ^{0}**C**
Inlet temperature	530 ^{0}**C**	257 ^{0}**C**
Mass flow rate	2330 TPH	1725 TPH
Specific heat	1170.4 J/kg.k	5200 J/kg.k

IV. DESIGN PROCEDURE OF ECONOMISER [10]

$$Q_{econ} = m_g C_{p,g}(T_{g1} - T_{g2}) = m_{fw} C_{p,fw}(T_{sat} - T_{fw}) \quad (1)$$

$$\Delta T_{lmtd} = \frac{\Delta T_i - \Delta T_e}{\ln \frac{\Delta T_i}{\Delta T_e}} \quad (2)$$

$$\frac{\Delta T_i}{\Delta T_e} = \frac{(T_{g1} - T_{sat})}{T_{g2} - T_{fw}}$$

$$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \quad (3)$$

$$m_{fw} = \left(n\frac{\pi}{4} d_i^{\,2} \right) \frac{V_{fw}}{v_f} \quad (4)$$

V_{fw} = Velocity of fluid at exit

v_f = Specific volume of saturated water

n=number of coils needed in the Economizer.

$$\dot{V} = \textit{Volume}\ \text{flow of the fluid} = m_{fw} v_f = A_i V_{fw} \quad (5)$$

$$\textit{number}\ \text{of turns of one coil}\ \mathrm{n}_t = \frac{1}{B - 2C} \quad (6)$$

Where B=Width, C=Clearance is given on two sides of the gas duct

$$\textit{height}\ \text{of duct occupied by the economizer (h)} = \mathrm{n}_t * \mathrm{P}\textit{itch} \quad (7)$$

Determination of overall heat transfer coefficient:

$Q = Q_{fg} = Q_{fw} = U \times A \times T^* \times F$ (8)

T* is the log mean temperature difference

F is the correction factor for the cross flow heat exchanger

$T^* = \{(T_{in}-t_{out})-(T_{out}-t_{in})\}/\ln\{(T_{in}-t_{out})/(T_{out}-t_{in})\}$

Dry flue gas loss= 100(CO2+CO)[C/100+S/267- C in A] x 30.6(T3-T4)/12 KJ/Kg (9)

Where

CO2, CO = % by volume

C = carbon content per unit mass of the fuel

S =sulphur content per unit mass of the fuel

C in A =combustible in ash per unit mass of fuel

30.6 = average kilogram molecular specific heat of gases

Wet flue gas loss = (M +9H)/100[4.2(25-T4) +2442+1.88(T3-25)] KJ/Kg (10)

For gas, the moisture in the fuel is already in the vapour form. So,

Wet flue gas loss = (M+9H)/100[1.88(T3-T4)+9H/100][4.2(25-T3)+2442+1.88(T3-25) KJ/Kg (11)

Sensible heat loss= wet flue gas – (GCV-NCV) KJ/Kg (12)

SHWV = [GCV-NCV] = WFG- [GCV-NCV] (13)

Radiation loss = [NCV x Factor X]/ GCV KJ/Kg (14)

Where Factor X= (GCV-GCV mr)/GCV

Table 2: Calculation Results before and after modification of Economizer

Parameters	Boiler Before Modification	Boiler after Modification in **Subcritical operating Mode**	Boiler after Modification in **Supercritical Operating Mode**
Proximate analysis on air dried basis			
Material	**Percentage (%)**	**Percentage (%)**	**Percentage (%)**
Ash	34	32	27
Moisture	9	10	10
Volatile matter	23.33	21.46	20.66
Fixed Carbon	35	36.54	37
Ultimate analysis on air dried basis			
Material	**Percentage** (%)	**Percentage (%)**	
Free Carbon	47	43	41
Hydrogen	3.1	2.82	2.52
Sulphur	0.6	0.38	0.28
Nitrogen	0.84	0.95	0.98
Oxygen	8.2	8.84	9.2
Air Preheater Outlet analysis of flue gases			
Gas	**Percentage** (%)	**Percentage** (%)	
Carbon dioxide	14	12	11.9
Oxygen	3.8	4.5	5.5
Nitrogen	80.4	83.5	85.4
Carbon monoxide	0	0	0
T3= Air heater gas outlet Temp.	142 ^{0}C	**136**^{0}C	**130**^{0}C
T4= Air heater at FD inlet duct	30 ^{0}C	**30**^{0}C	**30**^{0}C
GCV mr = GCV of the mill rejected	1500 kcal/kg	1500Kcal/kg	1500Kcal/kg
Distribution of ash			
Rough ash or furnace bottom ash	20%	20%	15%
Pulverized ash or fine ash	80%	80%	60%
Unburnt Carbon			
Un burnt carbon in bottom ash	2.0%	1%	0.78%
Un burnt carbon in fly ash	0.5%	0.5%	0.39%
Rough ash (FBA)	6.8% of coal	6.4%	6.0%
Pulverized ash (PFA)	27.2 % of coal	25.6%	23.2%
Carbon in rough ash	0.00136 kg/kg of coal	0.00064 kg/kg of coal	0.00045 kg/kg of coal
Carbon in fly ash	0.00136 kg/kg of coal	0.00128 kg/kg of coal	0.00119 kg/kg of coal
Total carbon in ash	0.00272 kg/kg of coal	0.00192 kg/kg of coal	0.00172 kg/kg of coal
Combustion Losses			
Dry flue gas loss	4.1%	3.05%	2.9%
Wet flue gas loss	5.09%	4.874%	4.5%
Sensible heat in water vapour loss	1.487%	1.604%	1.65%
Radiation losses	0.646%	0.649%	0.69%
Efficiency of the boiler	**88.67%**	**89.82%**	**91.23%**

Table 3: Costs involved in the Erection of additional banks of tubes:

S.NO	**Material cost**	**Costs**
1	Cost of each coil (pair)	79,200 /-
2	Total no. of pairs	78

3	Total cost for 78 pairs	78 x 79,200/- =61.7/- lakh
	Welding cost	
1	Cast of welding per joint	700/-
2	No. of joints per pair	**8**
3	Total no. of joints	8 x 78=624/-
4	Total cost of welding	624 x 700/- = 4.36/- lakh
	Welding material cost	
1	No. of electrodes consumed per joint	6x30/-
2	Cost of filler material per joint	37.63/-
3	Total cost of welding material per joint is	67.63/-
4	Total cost for 624 joints	0.422/- lakh
	Lifting cost	
1	Cost of lifting per pair	5000/-
2	Total lifting cost	5000 x 78 = 3.9/- lakh
3	Total cost = sum of all above costs	70.3/- lakh

Table 4: Savings with Modified Economiser

1	Monetary gain by improvement in efficiency of boiler by 1%	1, 00,000/- per day (approx)
2	Increase in the ID Fan input electric power is 60 KW per day	1400/- per day (approx)
3	Payback period is **75** days (approx).	Gain per day by incorporating additional bank of economizer tubes is (1, 00, 000-1400) = 98,600/- per day

V. LIMITATIONS THAT ARE OVERCOME WITH MODIFIED ECONOMISER

There are certain limitations on the feed water outlet temperature and the flue gas outlet temperature:-

1. The feed water outlet temperature should always be less than the saturation temperature of water at respective pressure prevailing in the economizer since the steam should not be formed in the economizer. Here, the saturation temperature at 180 kg/cm^2 pressure is 368 ^{0}Cwhich is very much higher than 308 ^{0}C.

2. The flue gas temperature should not be below 132.23 ^{0}C as the sulphur content in it gets liquidized below it and get deposited on the chimney walls and enhance the stack erosion. Here, the flue gas temperature at stack inlet is 136 ^{0}C which is more than 132.2^{0}C

Here, the both limitations are overcome. Therefore the additional bank of tubes in Economiser can be incorporated successfully.

VI. CONCLUSIONS

The following are observed after assumption of incorporation of additional bank of tubes in the economizer:

1. The feed water temperature increased by 4^{0}C in subcritical operating parameters and 22 ^{0}C in Supercritical operating parameters
2. The flue gas exit temperature decreased by 4 ^{0}C in subcritical operating parameters and 33 ^{0}C in Supercritical operating parameters
3. The efficiency of the boiler increased by 1-1.5%.in subcritical operating parameters 2 to 2.5% in Supercritical operating parameters
4. Monetary gain of 98,600/- per day
5. Amount of coal supplied can be reduced

Table 5: Comparative Results of Economizer before and after the modification

S.No	Parameter	Before Modification	After Modification in Subcritical pararameters	After Modification in Supercritical pararameters
1	Feed Water Outlet Temperature	304 ^{0}C	308 ^{0}C	326^{0}C
2	Flue Gas Outlet temperature	257 ^{0}C	253 ^{0}C	224^{0}C
3	Boiler Efficiency	88.6%	89.8%	91.23%
4	Total Losses	11.4%	10.2%	9.2%
5	Increase to be made in ID fan Power Supply=60 KW/day=1400/-/day			
6	Monetary gain for the increase of boiler efficiency = 1,00,000 /day			
7	Net gain by the incorporation of additional tubes in economizer=98,600/day			

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