

Improved Performance of a Industrial Packaged Boiler by Use of Economizer

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ABSTRACT: In the present scenario energy losses in the industrial boilers are major problems so carryout energy audit at Anish chemicals Gidc chitra, at Bhavnagar. By energy Audit calculated boiler efficiency and major losses in plant and this work is completed . We can improved boiler efficiency by utilize economizer and give maximum cost benefit analysis. The value of boiler efficiency and different losses are calculated at Anish chemicals .It is a combined water and fire tube boiler using biomass coal as fuel. Boiler efficiency calculated by direct method is in range of (78.5% to 81.6%). Major losses from boiler are heat loss due to radiation and convection from non insulated surfaces (4.8% to 6.3%), heat loss due to flue gas (6.3% to 6.4%), heat loss due to blow down (0.263 to 0.398%), heat loss due to incomplete combustion (1.87% to 2.21%), heat loss due to unburnt coal in bottom ash (1.74 % to 1.86)and heat loss due to moisture present in fuel (1.3% to 1.6%).Shell and tube type heat exchanger (economizer) was designed to recover heat loss due to flue gas by reducing flue gas discharge temperature. Kern method was used for heat exchanger calculations.

KEYWORDS: Boiler Efficiency, different losses, economizer

I. INTRODUCTION

In order to ensure that only products of the finest quality rolls out of Anish Chemicals, they have invested in an elaborate state-of-the-art infrastructure that spreads across a wide plot area and encompasses all the requisite machinery and production technology necessary for the production of high grade chemicals. Moreover, to ensure that everything is carried out in a streamlined manner they have segregated their entire infrastructural set up into different sections, viz, manufacturing unit, research & development labs, quality testing department and warehousing unit. Each of these units are supervised by able professionals with immense knowledge and experience in their respective domains.

Working Principle Of Combined Water Tube And Fire Tube Boiler At Anish chemicals:

The boiler is a combined fire and water tube boiler which can produce steam at 17.5bar with maximum temperature 205°C. Feed water pump feeds water to boiler drum. The drum is a heat exchanger without gases at tubes inside and water at shell side. Hot water from bottom of drum is circulated to tube circuit inside the combustion zone of furnace. Thus within furnace water is at tubes inside and hot gases are at furnace wall inside. Steam water mixture is transferred to drum. Steam is collect at top in the drum and it is drawn to main steam line by main steam valve. Atmosphere air is drawn by F.D fan, air is heated by energy of flue gases in airpreheater. Heated air enters the combustion chamber, combustion of coal take place in combustion chamber. Hot gases transfers heat to water inside the tube circuit. A gas passes through tubes of drum and transfers sensible heat to water which is at shell side. Flue gases coming out of drum passes through air preheater, I.D fan and chimney.

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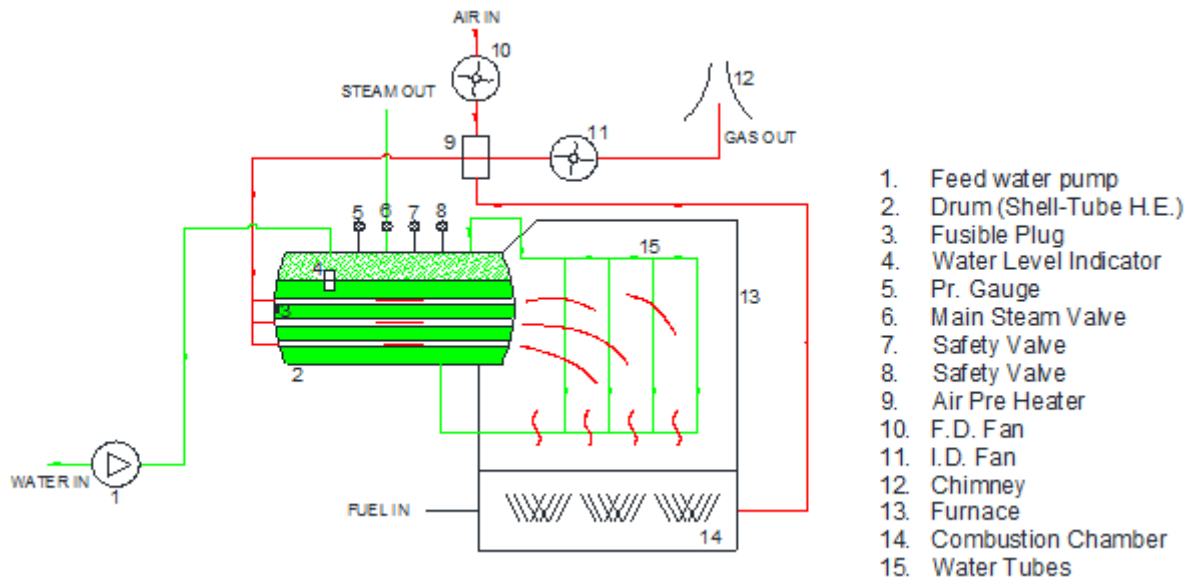
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Performance Evaluation Of Boilers:

Boiler efficiency, equivalent evaporation and factor of evaporation are performance parameter for boiler.

Flow Diagram Of Boiler:



II. BOILER EFFICIENCY TEST METHODS

Boiler efficiency can be tested by the following two methods:

- 1) **The direct method:** Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel.
- 2) **The indirect method:** Where the efficiency is the difference between the losses and the energy input.

The direct Method:

This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e. fuel) for evaluating the efficiency. Efficiency can be evaluated using the formula.

$$\text{Boiler Efficiency } (\eta) = \frac{Q \times (h_g - h_f)}{q \times GCV} \times 100$$

Indirect Method Or Heat Loss Method:

In the heat loss method the efficiency is the difference between the losses and the energy input. In indirect method the efficiency can be measured easily by measuring all the losses occurring in the boilers.

The Following Losses Are Applicable To Liquid, Gas And Solid Fired Boiler

- 11- Loss due to dry flue gas (sensible heat)
- 12- Loss due to hydrogen in fuel (H₂)
- 13- Loss due to moisture in fuel (H₂O)

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- 14- Loss due to moisture in air (H₂O)
- 15- Loss due to carbon monoxide (CO)
- 16- Loss due to surface radiation, convection and other unaccounted*.

Losses Which Are Insignificant And Are Difficult To Measure.

- 17- Unburnt losses in fly ash (Carbon)
- 18- Unburnt losses in bottom ash (Carbon)

Boiler Efficiency by indirect method = 100 – (11+12+13+14+15+16+17+18)

Boiler efficiency, η = 100 - (Total loss in%)

Boiler Efficiency Calculation By Indirect Method:

In order to calculate the boiler efficiency by indirect method, all the losses that occur in the boiler must be established. These losses are conveniently related to the amount of fuel burnt. In this way it is easy to compare the performance of various boilers with different ratings. The various losses associated with the operation of a boiler are discussed below with required formula.

1. Heat Loss Due To Dry Flue Gas: ([14] Page 9)

This is the greatest boiler loss and can be calculated with the following formula:

$$L_1 = \frac{m \times cp \times (T_f - T_a)}{GCV \text{ of fuel}} \times 100$$

2. Heat Loss Due To Evaporation Of Water Formed Due To H₂ in Fuel: ([14] Page 10)

The combustion of hydrogen causes a heat loss because the product of combustion is water. This water is converted to steam and this carries away heat in the form of its latent heat.

$$L_2 = \frac{9 \times H_2 \times \{584 + C_p (T_f - T_a)\}}{GCV \text{ of fuel}} \times 100$$

3. Heat Loss Due To Moisture Present In Fuel: ([14] Page 10)

Moisture entering the boiler with the fuel leaves as a superheated vapour. This moisture loss is made up of the sensible heat to bring the moisture to boiling point, the latent heat of evaporation of the moisture, and the superheater required to bring this steam to the temperature of the exhaust gas. This loss can be calculated with the following formula.

$$L_3 = \frac{M \times \{584 + C_p (T_f - T_a)\}}{GCV \text{ of fuel}} \times 100$$

4. Heat Loss Due To Moisture Present In Air: ([14] Page 11)

Vapour in the form of humidity in the incoming air, is superheated as it passes through the boiler. Since this heat passes up the stack, it must be included as a boiler loss. To relate this loss to the mass of coal burned, the moisture content of the combustion air and the amount of air supplied per unit mass of coal burned must be known. The mass of vapour that

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air contains can be obtained from psychometric charts.

$$L_4 = \frac{AAS \times \text{humidity factor} \times C_p \times (T_f - T_a)}{GCV \text{ of fuel}} \times 100$$

5. Heat Loss Due To Incomplete Combustion: ([14] Page11)

Products formed by incomplete combustion could be mixed with oxygen and burned a gain with further release of energy. Such products include CO, H₂, and various hydrocarbons and are generally found in the flue gas of the boilers. Carbon monoxide is the only gas whose concentration can be determined conveniently in a boiler plant test.

$$L_5 = \frac{\%CO \times C}{\%CO + \%CO_2} \times \frac{5744}{GCV \text{ of fuel}} \times 100$$

6. Heat Loss Due To Radiation And Convection: ([14] Page 12)

The other heat losses from a boiler consist of the loss of heat by radiation and convection from the boiler casting into the surrounding boiler house. Normally surface loss and other unaccounted losses is assumed based on the type and size of the boiler as given below. However it can be calculated if the surface area of boiler and its surface temperature are known as given below:

$$L_6 = 0.548 \times \left[\left(\frac{T_s}{55.55} \right)^4 - \left(\frac{T_a}{55.55} \right)^4 \right] + 1.957 \times (T_s - T_a)^{1.25} \times \sqrt{\frac{(196.85 V_m + 68.9)}{68.9}}$$

7. Heat Loss Due To Unburnt In Fly Ash: ([14] Page 13)

Small amounts of carbon will be left in the ash and this constitutes a loss of potential heat In the fuel. To assess these heat losses , samples of ash must be analysed for carbon content. The quantity of ash produced per unit of fuel must also be known.

$$L_7 = \frac{\text{Total ash collected / kg of fuel burnt} \times GCV \text{ of fly ash}}{GCV \text{ of fuel}} \times 100$$

8. Heat Loss Due To Unburnt In Bottom Ash :([14] Page 13)

$$L_8 = \frac{\text{Total ash collected / kg of fuel burnt} \times GCV \text{ of bottom ash}}{GCV \text{ of fuel}} \times 100$$

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Boiler Analysis

Sr. No.	Parameters	Week 1	Week 2	Week 3	Week 4
1	Fuel firing rate(kg/hr)	60.55	61.74	65.32	64.20
2	Steam generation rate(kg/hr)	290	280	306	305.3
3	Steam pressure(kg/cm ² (g))	4	4	4	4
4	Steam temperature(⁰ C)	156	160	161	158
5	Feed water temperature(⁰ C)	65	64.34	65.66	66
6	Surface temperature of boiler Furnace wall(⁰ C)	44	45	44	43
7	Wind velocity around the boiler(m/s)	3.09	3.06	3.01	3.09
8	Total surface area of boiler furnace (m ²)	24.25	24.25	24.25	24.25
9	Surface area of flue gas duct(m ²)	9.1	9.1	9.1	9.1
10	water loss during blow down(kg/hr)	61.83	64.46	69.3	70
11	Temperature of water leaving boiler(⁰ C)	74	76	77.8	79
12	Surface temperature of flue gas duct wall (⁰ C)	73	74	72	73

Result Analysis

Sr. no	Parameters (%)	Week 1	Week 2	Week 3	Week 4
1	L1	6.3	5.9	5.19	4.8
2	L2	6.33	6.4	6.13	6.3
3	L3	0.263	0.351	0.367	0.398
4	L4	1.87	2.21	2.02	2.20
5	L5	1.8	1.86	1.74	1.84
6	L6	1.3	1.56	1.3	1.6
7	Boiler efficiency	81.6	78.5	80.2	79.6

II. ECONOMISER DESIGN

Flue gas final discharge temperature is 155°C, which is the reason for high heat loss in flue gas. To recover the heat energy of flue gas it is suggested to use economiser (heat exchanger) which will pre-heat the feed water before it enters the drum.

(a) ECONOMISER FLUID TEMPERATURES:

Flue gas entry temp. $T_1 = 180^\circ \text{C} = 356^\circ \text{F}$
 Consider Flue gas exit temp. $T_2 = 155^\circ \text{C} = 311^\circ \text{F}$
 Feed water entry temp. $t_1 = 65^\circ \text{C} = 149^\circ \text{F}$
 Feed water exit temp. $t_2 = ?$

$$m_g C_{pg} \Delta T_g = m_w C_{pw} \Delta T_w$$

$$470.6 \times 10.17 \times 25 = 290 \times 4190 \times \Delta T_w$$

$$\Delta T_w = 9.84^\circ \text{C} = t_1 - t_2$$

$$t_2 = 74.84^\circ \text{C} = 166.72^\circ \text{F}$$

(b) HEAT DUTY OF HEAT EXCHANGER:

$$Q = m_g C_{pg} \Delta T_g = m_w C_{pw} \Delta T_w$$

$$= 470.6 \times 1017 \times 25 \text{ J/hr}$$

$$= 3323.6 \text{ J/sec.} = 11340.12 \text{ Btu/h}$$

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- Properties of water at mean Temp $= \frac{149+166.72}{2} = 157.86^\circ \text{F}$
 $K_w = 0.384 \quad \text{Btu} / (\text{hr. Ft.}^\circ \text{F})$
 $C_w = 1 \quad \text{Btu} / (\text{L}_b^\circ \text{F})$
 $\mu_w = 0.97 \quad \text{L}_b / (\text{Ft. hr})$
- Properties of gas (air) at mean Temp $= \frac{356+311}{2} = 333.5^\circ \text{F}$
 $K_g = 0.0208 \quad \text{Btu} / (\text{hr. Ft.}^\circ \text{F})$
 $\mu_g = 0.0587 \quad \text{L}_b / (\text{Ft. hr})$
 $C_g = 0.244 \quad \text{Btu} / (\text{L}_b^\circ \text{F})$
 We will use Kern method for heat exchanger design [16].

(c) HEAT TRANSFER AREA CALCULATION:

$$A = \frac{Q}{U_{assu} \times LMTD \times F_T}$$

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\log_e \frac{\Delta T_1}{\Delta T_2}}$$

Where $\Delta T_1 = T_1 - t_2 = 189.28^\circ \text{F}$

$\Delta T_2 = T_2 - t_1 = 162^\circ \text{F}$

$$LMTD = \frac{189.28 - 162}{\log_e \frac{189.28}{162}} = 170.5^\circ \text{F}$$

For heat exchanger with liquid outside (inside) and gas at atmospheric pressure inside (outside) tubes

$U_{assu} = 3 \text{ to } 15 \text{ Btu} / (\text{hr. Ft.}^2 \text{F})$ ([16] page 840)

Taking $U_{assu} = 7.5 \text{ Btu} / (\text{hr. Ft.}^2 \text{F})$

and $F_T = 0.9$

Putting values in equation for A

$$A = 9.85 \text{ Ft}^2$$

(d) HEAT EXCHANGER TUBES AND SHELL:

Let us assume 1 shell pass 2 tube pass exchanger with 1" tube O.D, 0.834" tube I.D. 2.5' tube length and 1¼" Square Pitch tube arrangement ([16] page 841 - 843)

(e) CALCULATED HEAT TRANSFER CO-EFFICIENT:

Considering gas at tube side and water at shell side because gas has higher fouling tendency

$$nt = \frac{A}{\pi \times d \times L} = \frac{9.85 \times 12}{\pi \times 1 \times 2.5}$$

$$nt = 15.06 \text{ tubes}$$

So selecting 8" shell diameter and 16 no. of tubes (1" outer dia)

$$\text{Now } Re_g = \frac{4mg \frac{np}{nt}}{\pi d i \mu_g}$$

Putting values

$$Re_g = 15622.8$$

Calculating internal heat transfer co-efficient. (gas side)

For $Re_g = 15622.8$ $J_{Hg} = 55$ ([16] page 834)

$$J_{Hg} = \frac{h_i d_i}{K_g} \left(\frac{\mu_g C_g}{K_g} \right)^{-1/3} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

Considering $\frac{\mu}{\mu_w} = 1$ and putting values

$$h_i = 14.47 \text{ Btu.} / (\text{hr. Ft}^2 .^\circ \text{F})$$

Calculating external heat transfer co-efficient (water side)

We have taken 8" shell with 25% cut segment.

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Baffles spacing $B = 0.5$, $D_s = 4''$

$$\text{Now } De = \frac{4(P_t - \frac{\pi}{4}d_o^2)}{\pi d_o}$$

Putting values

$$De = 0.081'$$

$$a_s = \frac{(P_t - d_o)B D_s}{P_t}$$

Putting values

$$a_s = 0.0444 \text{ Ft}^2$$

$$\begin{aligned} \text{Mass velocity } G_s &= \frac{m_g}{a_s} \\ &= 14402.5 \text{ Lbs / (hr.Ft}^2) \end{aligned}$$

$$Re_w = \frac{D_e G_s}{\mu_w}$$

Putting values

$$Re_w = 1202.68$$

Now, $J_{Hw} = 17$ for $Re_w = 1202.68$ ([16] page 838)

$$J_{Hw} = \frac{h_o D_e}{K_w} \left(\frac{\mu_w C_w}{K_w} \right)^{-1/3} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

Considering $\frac{\mu}{\mu_w} = 1$ and putting values

$$h_o = 109.63 \text{ Btu / (hr Ft}^2 \text{ }^\circ\text{F)}$$

Considering Carbon Steel tube (Plain Carbon Mn $\leq 1\%$, Si $\leq 0.1\%$)

$$K_{wall} = 35.1 \text{ Btu / (hr Ft}^2 \text{ }^\circ\text{F)}$$

$$\text{and } Rd_w = Rd_g = 0.001 \text{ Ft}^2 \text{ h}^\circ\text{F/Btu}$$

$$\frac{1}{U_{cal}} = \frac{1}{h_o} + Rd_w + \frac{A_o(d_o - d_i)}{A_i 2K_{wall}} + \frac{A_o(1)}{A_i h_i} + \frac{A_o}{A_i} Rd_g$$

Putting values

$$U_{cal} = 8.982 \text{ Btu / (hr Ft}^2 \text{ }^\circ\text{F)}$$

$$\begin{aligned} \text{Now } \frac{U_{cal} - U_{assu}}{U_{assu}} &= \frac{8.982 - 7.5}{7.5} \\ &= 0.1976 \\ &= 19.76\% \end{aligned}$$

Which is less than 30 %, so our design is acceptable

Heat exchanger (economizer) data :

1 shell pass 2 tube pass

Shell dia 8", tube dia 1 "

Tube length 2.5'

no. of tubes 16

Tube material Carbon steel

(Plain carbon steel Mn $\leq 1\%$, Si $\leq 0.1\%$)

(e) **PAY BACK TIME:**

Energy saved by using economizer

$$= 3223.0 \text{ Watts}$$

$$= 3.224 \text{ KW}$$

Yearly energy saving considering 12 hr/day working and 300 days/ year

$$= 3.224 \times 12 \times 3600 \times 300 \text{ KJ}$$

$$= 51783040 \text{ KJ}$$

$$= 11606.4 \text{ KW. hr}$$

- Calorific value of coal is 3492 Kcal/Kg and price of coal = 4.5 Rs/Kg Considering boiler efficiency = 81.6 %

$$\text{Cost of energy} = \frac{4.5 \times 3600}{3492 \times 0.81 \times 4.186}$$

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$$= 1.385 \text{ Rs/ KW.hr}$$

$$\text{Annual monetary saving by economizer} = 11606.4 \times 1.385 = 16074.5 \text{ Rs.}$$

Cost of economizer:

Price of 1" plain carbon steel ($\text{Mn} \leq 1\%$, $\text{Si} \leq 0.1\%$) tube

$$= 1150 \text{ US\$ / Ton}$$

$$= \frac{1150 \times 66.2}{1000}$$

$$= 76.13 \text{ Rs/ Kg}$$

$$\text{Total length of tube required} = 16 \times 2.5 = 40'$$

$$\text{Weight of 1" O.D, 0.834" I.D. tube} = 0.813 \text{ lbs/feet}$$

$$\text{So weight of 40 feet tube} = 40 \times 0.813 \times 0.454 = 14.76 \text{ Kg}$$

$$\text{Cost of tubes} = 15 \times 76.13 = 1142 \text{ Rs}$$

$$\text{Cost of shell end cover and buffels} = 3000 \text{ Rs.}$$

$$\text{Cost of fabrication} = 2500 \text{ Rs.}$$

$$\text{Total cost of economizer} = 1142 + 3000 + 2500 = 6642 \text{ Rs.}$$

So payback time for economizer

$$= \frac{6642}{16074.5} \times 365$$

$$= 150.8 \text{ days} = 5 \text{ months}$$

III. CONCLUSION

1. Boiler efficiency was calculated by direct method. In direct method efficiency is calculated as ratio of boiler output to boiler input, without calculating individual loss Boiler output is equal to enthalpy rise of feed water when it is converted to superheated steam. Boiler input is amount of energy supplied in the form of energy of fuel. Boiler efficiency calculated by this method is 78.5 to 81.6%.

2. Major energy losses in boiler are:

a) Heat loss due to radiation and convection: Heat loss due to radiation and convection from insulated surface is 4.8% to 6.3% as a large area of flue gas duct and furnace is not insulated radiation and convective losses are high.

b) Heat loss due to flue gas: Higher flue gas Discharge temperature is (153.9° C to 155.8° C) results in higher heat loss due to flue gas (6.3% to 6.4%).

c) Heat loss due to moisture present in fuel: Heat loss due to moisture in fuel is (1.3% to 1.6%) .Fuel energy utilized to evaporate moisture present in fuel results in loss.

d) Heat loss due to incomplete combustion: Heat loss due to incomplete combustion (1.87% to 2.21%). For effective conversion of chemical energy of fuel in to heat energy the combustion should be complete combustion. Combustion quality depends upon amount of air supplied, air velocity, air temperature, fuel size and fuel distribution etc. Higher CO% in flue gases indicated incomplete combustion.

e) Heat loss due to unburnt coal in bottom ash: Heat loss due to unburnt coal in bottom ash (1.74% to 1.86%). Some coal is left unburnt and discharged with ash, results in energy loss.

f) Heat loss due to blow down: Heat loss due to blow down(0.263% to 0.398%). blow down of hot boiler water is carried out to control concentration of dissolved solids and to remove sludge from water. Hot water discharged during blow down results in heat losses.

3. To recover heat loss due to flue gas it was suggested to use shell and tube type heat exchanger as economizer. It was designed using Kern method. Payback time for heat exchanger is 5 months.

IV. FUTURE WORK

Energy loss due to moisture content in coal is 1.3% to 1.6% . so suitable type of coal dryer should be used to reduce energy loss due to moisture. Proper maintenance: A detailed maintenance plan should be prepared and implemented. It should include preventive and predictive maintenance activities. Boiler, air-preheater and economizer tubes are critical parts. Tube cleaning, leak test and wall thickness analysis should be carried out according to maintenance plan. Wall

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thickness measurement and corrosion check must be carried out for components of flue gas path. Vibration analysis would lead to better boiler performance. Size of coal used is 120 to 160 mm length and 50 to 60 mm dia. Size suggested by Bureau of energy efficiency is 25 to 40 mm. It is suggested to reduce coal size to improve combustion quality and efficiency of Boiler.

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