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Energy Audit of Boiler: Awash Melkassa Aluminum Sulphate and Sulphuric Acid Industry

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Abstract:*Boiler is one of the first energy-consuming parts of any process industry or power plant. And, its efficiency deteriorates with time, due to poor combustion, heat transfer fouling and inappropriate operation and maintenance. Moreover, fuel quality and water quality also lead to the poor performance of the boiler. Hence, efficiency testing helps us to find out how far the boiler efficiency drifts away from the best efficiency. In this work, a complete energy auditing of the boiler was carried out at Awash Melkassa Aluminum Sulphate and Sulphuric Acid Company by ASME (American Society for Mechanical Engineers) power test code, PTC 4.1. It suggests two methods, the first method is the input-output method, and the second method is the heat loss method, but the latter is the more reliable one. The first method showed a drift of 4.4 %, and the second method showed a drift of 9.06 % from the best efficiency of the boiler. Through a complete energy audit, it was reported that 13.71 %, i.e., 1439.55 kCal/kg of fuel burnt, input heat energy is carried away with dry flue gasses.*

Key Word:*Energy Auditing, Boiler efficiency, Direct Method, Indirect Method, Awash Melkassa Aluminum Sulphate and Sulphuric Acid Company.*

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I. Introduction

The type of boiler used by the factory is SM/FB 600/15/N fire tube steam boiler, Italian made. Its mainly used to supply superheated steam to the production process of the factory. A boiler plant is a prominent place for energy-saving opportunities in any factory. And, through an energy audit, reduction in energy expenditure could be achieved. It is also an effective means to develop plans and to achieve goals in energy saving.

AkramAvami et al. [1] did on-site energy auditing of over 30 cement firms and reported following energy-saving potentials: electricity savings of 223.5*106kWh and fuel oil savings of 168*106 Liters. Khurana et al. [2], through energy audit of cement plant in Indiana, reported 35 % of the input energy was being lost with the waste heat streams. Luo Chao et al. [3] proposed a new method to find the efficiency of the boiler, where the efficiency is the function of exhaust gas and inlet air temperatures. Wang Kun et al. [4] prescribed a plan to modify the chain-grate boiler with pulverized coal combined combustion, and the heat efficiency improved. BrundabanPatro [5], through energy audit on combination tube boilers, observed the heat loss due to unburnt carbon in the bottom ash is significant and couldn’t be ignored. Kljajic et al. [6] employed a neural network model to predict the boiler efficiency. In this work, an attempt was made to determine the efficiency and the significant losses in the boiler.

II. Boiler Data Collection

To perform the energy audit, and to assess the efficiency of the boiler, the following data/measurements are required:

1.Boiler dimensions (Table 1 shows the complete specification of the boiler) and surface temperature.
2.Feedwater flow rate and temperature.
3.Boiler steam pressure, temperature, and flow rate.
4.Combustion air temperature.
5.Ambient temperature.
6.Fuel oil flow rate and pre-heating temperature.
7.Flue gas temperature and constituents percentage of combustion products.

The different data related to steam generation and utilization of the boiler were collected by:
1.Directly measured using portable instruments like portable combustion analyzer (PCA), infrared and dual K contact thermometer, and ultrasonic flow meter.
2.Directly recorded from the factory boiler control panel.
3.Referred to different factory record book and log sheets.
4. By Interviewing factory workers.

i- Flue gas data:

Portable Combustion Analyzer (PCA) was used to analyze combustion for tune-ups, maintenance, and emissions monitoring. PCA has the capability of measuring, displaying, and storing combustion tests. It shows oxygen content, carbon dioxide content, carbon monoxide content, air temperature, flue gas temperature, stack loss, and the fuel type to be monitored. The stack and combustion air temperatures were measured using K type thermocouples, and the draft pressure was measured using the pressure transducer. An in-built computer performs the combustion calculations and shows the results of constituents of gases and draft pressure. Table 2 represents the flue gas data.

Table 1:Specification of the boiler.

	Specifications
Type	Fire tube
Model	SM/FB 600/15/N
Boiler rated capacity (TPH)	6
Actual steam generation (TPH)	5.7
Rated design pressure (bar)	15
Test pressure (bar)	14.7
Actual steam generation pressure	12.5
Actual steam generation temperature (^oC)	187.4
Feedwater temperature (^oC)	80
Blowdown (automatic) liter/min	0.697
Efficiency (%)	Net 93.3, gross 86.93
Local ambient temperature (^oC)	27
Average boiler surface temperature (^oC)	40
Diameter (m)	3
Length (m)	4
The total surface area of the boiler exposed to ambient (m^2)	51.8
Wind speed (m/sec)	4.2
Fuel oil consumption (TPH)	0.38

Table 2: Flue gas data

Element	Reading
O_2 in flue gas (volume %)	8
Flue gas CO2 (volume %)	7.8
Flue gas temperature (^oC)	228
Ambient temperature (^oC)	27
Stack temperature (^oC)	230
CO (volume %)	0.11
Specific Heat of Flue gas (kCal/kg)	0.33

ii- Boiler surface data:

The boiler surface is relatively hotter than the ambient air, and as a result, convective surface losses will occur. Surface temperatures are measured at different locations using an infrared and dual K contact thermometers. Besides, blowdown and feedwater temperatures were also recorded. The data, as mentioned above, are tabulated in Table 3.

Table 3: Various required temperatures of the boiler.

Blowdown Temperature	115 ^{0}C
Feedwater Temperature	80 ^{0}C
Ambient Temperature	27 ^{0}C
Steam Produced	@ 187.4 ^{0}C
Average surface temperature	40 ^{0}C

iii. Ultimate analysis data of Furnace oil

The ultimate analysis was carried out to know the chemical and physical composition of the Furnace oil, and Table 4 describes the complete report of it.

Table 4: Ultimate analysis data.

Furnace oil composition	Ultimate Analysis (mass %)
Oxygen (O_2)	0.5
Nitrogen (N_2)	0.5
Hydrogen (H)	12
Carbon (C)	84
Sulfur (S)	1.5
Moisture (M)	0.5
Sp. gravity of oil	0.92
Gross Calorific Value = 43,961 kJ/kg (10,500 kcal/kg)	

III. Boiler Efficiency Calculations

Two methods can calculate the boiler efficiency: a) Direct method and b) Indirect method. The former is also known as the input-output method since it needs only the output steam produced and the heat input (i.e., energy from fuel combustion) for evaluating the efficiency. The main demerit of this method is that it doesn't tell why the efficiency is low, and where are the significant heat losses are occurring. The latter method addresses all these issues, and it is the most recommended by professionals.

i- Direct Method:

The direct method uses equation 1, to calculate the efficiency of the boiler:

$$\eta = \frac{Q*(H-h)}{q*GCV} * 100 \quad (1)$$

where,

Q=quantity of steam generated per hour = 5.7 TPH.

q=quantity of fuel used per hour = 0.38 TPH.

GCV= Gross calorific value of fuel = 10500 kCal/kg.

H= Enthalpy of steam = 662.73 kCal/kg.

h=Enthalpy of feed water = 85 kCal/kg.

Using the above formula, the efficiency turns out to be **82.53%.**

ii- Indirect Method:

The indirect method uses equation 2 to calculate the efficiency of the boiler:

$$\eta = 100 - (L_1 + L_2 + L_3 + L_4 + L_5 + L_6) \quad (2)$$

Where,

1. L_1 = % Heat loss due to dry flue gases, and is given by equation 3:

$$L_1 = \frac{m*C_p*(T_f - T_a)}{GCV\ of\ Fuel} * 100 \quad (3)$$

where,

m=mass of dry flue gases = Combustion products from fuel: CO_2 + SO_2 + Nitrogen in fuel + Nitrogen in the actual mass of air supplied + O_2 in flue gas (H_2O/Water-vapor in the flue gas should not be considered) = 21.71 kg / kg of fuel.
C_p=Specific heat of flue gas (kCal/kg) = 0.33 kCal/kg.
T_f=Temperature of Flue gas = 228 ^oC.
T_a=Ambient temperature = 27 ^oC.
Therefore, L_1 turns out to be 13.71%.
2.L_2 = % Heat loss due to evaporation of water formed due to H_2 in fuel, and is given by equation 4:

$$L_2 = \frac{9*H*\{584+C_p(T_f-T_a)\}}{GCV\ of\ Fuel} * 100 \qquad (4)$$

where,
H= kg of Hydrogen present in 1 kg of fuel = 0.12 kg / kg of fuel.
C_p=Specific heat of superheated steam (kcal/kg) = 0.55 kcal/kg.
Therefore, L_2 turns out to be 7.14 %.
3. L_3 = % Heat loss due to moisture present in the fuel, and is given by equation 5:

$$L_3 = \frac{M*\{584+C_p(T_f-T_a)\}}{GCV\ of\ Fuel} * 100 \qquad (5)$$

where,
M = kg of moisture in kg of fuel = 0.005 kg of moisture / kg of fuel
Therefore, L3 turns out to be 0.033 %.
4. L_4 = % Heat loss due to moisture present in the air, and is given by equation 6:

$$L_4 = \frac{AAS*Specific\ \ Humidity\ \ of air *C_p*(T_f-T_a)}{GCV\ of\ Fuel} * 100 \qquad (6)$$

where,
AAS = Actual Mass of air supplied per kg of fuel = 21.88 kg / kg of fuel.
Specific Humidity of air = 0.014 kg of moisture/kg of dry air.
C_p=Specific heat of superheated steam (kcal/kg) = 0.55 kcal/kg.
Therefore, L_4 turns out to be 0.32 %.
5. L_5 = % Heat loss due to partial combustion of C to CO, and is given by equation 7:

$$L_5 = \frac{\%CO*C}{\%CO+\%CO_2} * \frac{5744}{GCV\ of\ fuel} * 100 \qquad (7)$$

where,
CO = Volume of CO in flue gas (%) = 0.11.
CO_2 = Actual volume of CO_2in flue gas (%) = 7.8.
C = kg of Carbon present in 1 kg of fuel = 0.84 kg / kg of fuel.
Therefore, L_5 turns out to be 0.63 %.
6. L_6 = Heat loss due to radiation and convection in W/m^2, and is given byequation 8:

$$L_6 = 0.548[(\frac{T_s}{55.55})^4 - \left(\frac{T_a}{55.55}\right)^4\Big] + [1.957*(T_s-T_a)^{1.25} * \sqrt{\frac{196.85V_m+68.9}{68.9}}] \qquad (8)$$

where,
V_m = wind velocity in m/s = 4.2 m/s.
T_s = Surface Temperature in Kelvin = 313.15 K.
T_a = Ambient Temperature in Kelvin = 300.15 K.
Therefore, L_6 turns out to be 260.69 W/m2. To convert L_6 into %, useequation 9:
L_6 (%) = (L_6 (W/m^2) * 0.86 * Surface area of the Boiler) / (GCV of Fuel * Fuel firing rate)(9)
Therefore, L_6 turns out to be 0.29 %.
Thus, the efficiency of the boiler by the indirect method is **77.87 %.**

IV. Results And Discussion

Theabove calculations make it clear that; the indirect method is more efficient than the direct method.Moreover, the direct method doesn't provide any information regarding various losses accountable for various efficiency levels. Figure 1 represents the different losses from the boiler, and dry flue gasses loss is the most significant one among all and accounting to 13.71 % = 1439.55 kCal/kg of fuel burnt. 'L_2' loss is also one of the significant ones; it is inevitable. Remaining losses are comparatively insignificant and don't require major attention.

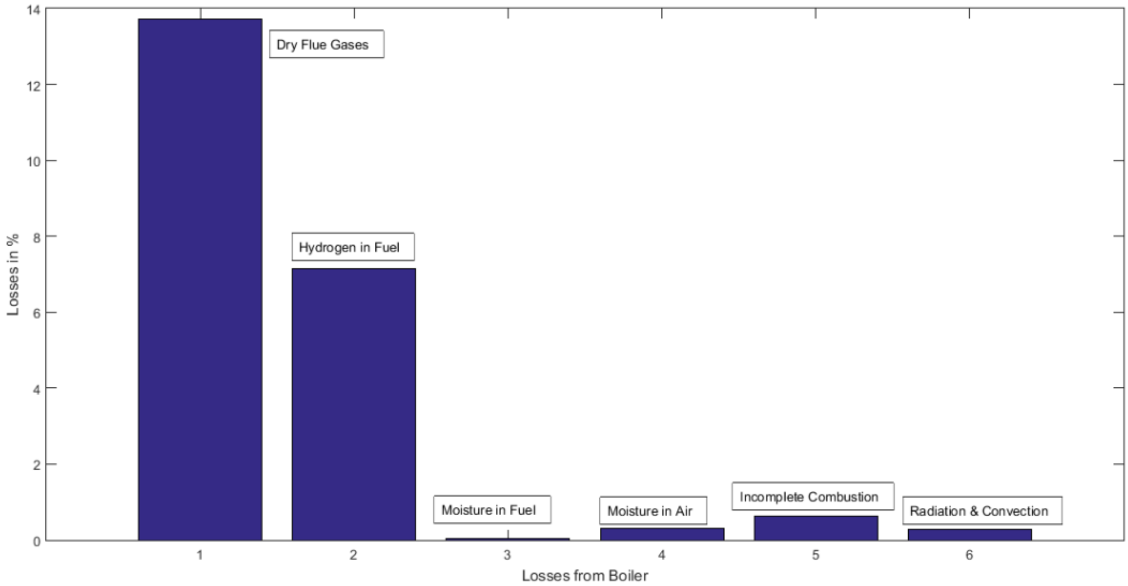

Fig. 1 Losses from the Boiler

V. Conclusion

A complete energy audit of the boiler at Awash Melkassa Aluminum Sulphate and Sulphuric Acid Company was carried out. It was observed that by the direct method, the boiler efficiency drifts by 4.4 % from the best efficiency. Whereas, the indirect method showed a drift of 9.06 %. This abnormal drift was due to the significant input energy loss carried away with the dry flue gasses. The heat loss due to dry flue gasses was 13.71 % of total heat input energy, i.e., 1439.55 kCal/kg of fuel burnt. It was reported to the facility managers to develop plans to achieve energy savings in this significant area.

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