Boiler Efficiency Analysis of A 220mw Steam Power Plant Using Direct Method

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***Abstract*: This paper presents a boiler efficiency analysis of a 220MW steam power plant using the direct method. The procedure employed to determine the boiler efficiency was done using the input-output method based on ASME PTC 4.1 standard. The experimental data used for the analysis were obtained from boilers installed in Egbin Thermal Power Plant located at Ikorodu, Lagos, Nigeria. Instantaneous data on boiler thermal efficiency can determine the condition of boiler operation, heat generation, and heat loss. It was established that boilers#-1, 2, 4, 5, and 6 have 72.51%, 67.66%, 69.50%, 78.16%, and 79.73% efficiencies respectively, which is an indication of good performance achieved through condition monitoring, combined with routine maintenance. Similarly, boiler#-2 and boiler#-6 have a 1.02 factor of evaporation, which tells that both boilers generate steam at the same rate when 1 kg of natural gas is burnt. In the same way, boiler#-1 and boiler#-4 have a 1.05 factor of evaporation when 1kg of natural gas is burnt to generate 16.13kg and 15.47 kg of steam respectively. Whereas boiler#-5 boiler has a factor of evaporation of 1.08 when 1 kg of natural gas is burnt to generate 17.40 kg of steam. Furthermore, a load factor of the various boilers indicates that each of the boilers can generate 73.31%, 99.32%, 97.05%, 76.16%, and 88.53% of its installed capacity respectively.**

***Keywords*: Efficiency, Boiler, Direct Method, Evaporation, Analysis, Maintenance, Thermal**

I. INTRODUCTION

A boiler is one of the high energy-consumption equipment to provide dry steam for power generation. The boilers installed at Egbin Power Plant are supercritical dual front fired, natural draught, and horizontal drum water tube of Babcock and Wilcox design. The boiler generates steam at high pressure of 12.5MPa and at a high temperature of 541^{0}C, the steam turbine converts the heat energy of the steam into mechanical energy. This analysis was carried out to determine the available present efficiency of the boilers and to compare them with design values stipulated in the Egbin power plant standard operating procedure. Hence, it is an indicator for tracking day-to-day and season-to-season variations in boilers efficiencies and energy efficiencies improvement [1].

Boiler efficiency is a measure of the goodness of the chosen process and equipment to transfer combustion heat in fuel to the heat in steam. Esa [2] defined boiler efficiency as the ratio of useful heat output to the sum of energy input. Boiler efficiency also known as fuel-to-steam efficiency or fuel-to-water efficiency estimates the relationship between the energy input and energy output of a boiler system. This proportion is expressed as a percentage and is utilized to assess the performance of the boiler and the burner as a way to decide the fuel expenses of boiler equipment and find out how far the boiler efficiency drifts away from the best efficiency. Any detected aberrations from design efficiency could therefore be examined to locate the trouble area for necessary corrective action. Hence, it is necessary to seek out the present level of efficiency for performance evaluation, which may be a prerequisite for energy conservation action in the industry [3] [1]. In another study by the Bureau of Energy Efficiency [1], poor combustion, heat transfer fouling, age, poor operations, and maintenance affect boiler efficiency, evaporation ratio as well as performance over time.

More so, deterioration of fuel quality and water quality also leads to poor performance of the boiler, and Indu [5] emphasizes that fuel type/analysis, excess air, flue gas temperature, and ambient temperature are some of the factors that affect boiler efficiency. Nonetheless, Indu [5] highlighted the main causes of heat losses in a boiler including the following; loss by fuel incomplete combustion, loss by defective combustion gas, loss by exhaust gas temperature, radiation, and convection losses from boiler surroundings.

Comprehension of boiler efficiency is important because it assists management and engineers make better strategic business and technical decisions about the equipment since operational fuel usage cost is the most important portion of investment compared to initial capital costs. Hence, fuel-to-steam efficiency is an important technical and economic factor that is directly proportional to boiler cost and energy saving. Thus, it helps forecast future fuel cost, and maintenance costs and implements best maintenance practices as well as determine the full life cycle of the boiler.

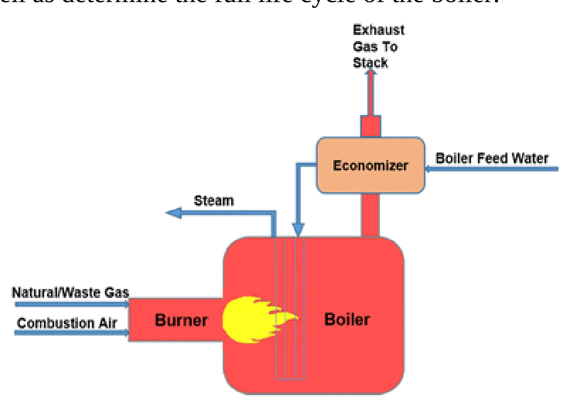

Figure 1: Simplified Schematic Diagram of a Gas fired Boiler [4].

A. Boiler Performance Determinants

Parameters that governed the performance of a boiler are grouped into those that decide boiler heat input and heat output. Essentially, the parameters that decide boiler heat input are; Fuel to be fired, fuel ultimate analysis, fuel moisture, the calorific value of fuel, ambient temperature, relative humidity, and sit altitude. While those that decide boiler heat output are; main steam flow, main steam temperature, main steam pressure, feed water temperature, and auxiliary steam consumption before the stop valve [5].

B. Reference Standards for Boiler Efficiency Calculation

According to ASME and John [6] [7], to calculate boiler efficiency, different reference standards are employed namely Indian Standard IS 8753, British Standard-BS845:1987, and USA Standard ASME PTC-4-1 Power Test Code. However, Indian Standard IS 8753 and British Standard BS 845 are designed for spot measurement of boiler efficiency while ASME PTC-4-1 approximates the stack losses of a boiler to evaluate its efficiency, and therefore, most of these standards do not include blowdown as a loss in the efficiency calculation. Thus, the formula used in this paperwork is centered on ASME PTC-4-1.

C. Types of Boiler Efficiency

The following designate Boiler Efficiency:

I. Combustion Efficiency

It shows the burner's capability to completely burn fuel indicated by the amount of unburned fuel and excess air in the exhaust. Fundamentally, if both the unburned fuel and excess air operate at low levels, then the burner system is considered efficient. More so, a well-designed burner will operate with 15 – 20% excess air and the desired range for combustion efficiency is 75% - 89% [7] [8].

II. Thermal Efficiency

It evaluates the heat exchanger's effectiveness by analyzing its ability to transfer thermal energy (heat) from the combustion process to the water or steam in the boiler drum. Nonetheless, thermal efficiency does not consider factors such as radiation and losses, and convection losses [8] [9].

III. Fuel to Steam Efficiency

According to John, A.K et al and Engineering Toolbox [7] [9] [10], fuel-to-steam efficiency is the general efficiency of a boiler including thermal efficiency, radiation, and convection losses, and therefore, the average values for fuel-to-Steam efficiency are usually between 80-85%. However, this efficiency is calculated using either of the two methods as prescribed by the ASME (American Society for Mechanical Engineers) power test code, PTC 4.1

D. Methods for Calculating Boiler Efficiency

Boiler efficiency can be calculated by two main methods as specified by John [7].

I. Direct Method (Input/output method)

This is also known as the input-output method or energy balance method because the only useful output (steam) and the heat input (fuel) are utilized for calculating efficiency. Hence, the energy gain in water or steam is compared with the energy content of fuel [5] [7].

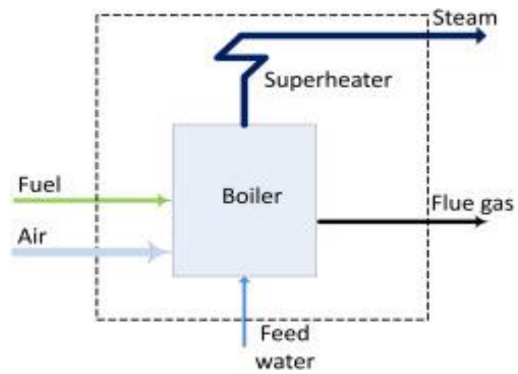

Figure 2: Direct Method Source: Bureau of energy efficiency [7].

The formula for this method according to ASME PTC 4.1 [3] is

$$Boiler\ Efficiency = \frac{Heat\ Output}{Heat\ Input} X\ 100$$

$$Boiler\ Efficiency = \frac{Heat\ adition\ to\ steam}{Gross\ Heat\ in\ Fuel} X\ 100$$

$$= \frac{Steam\ flow\ rate\ x\ (steam\ enthalpy - feed\ water\ enthalpy)}{Fuel\ firing\ rate\ x \frac{Gross}{Net}\ calorific\ value} X\ 100$$

$$\text{Boiler efficiency}, \eta\text{boiler} = \frac{\text{ms (hsup} - \text{hf1)}}{mf\ X\ CV\ of\ fuel} X\ 100$$

Where;

ms = stands for steam flow rate
h_{sup} = enthalpy of steam in KJ/Kg
h_{fi} = enthalpy of water in KJ/Kg
mf = fuel flow rate in T/H
CV= Gross calorific value of fuel KJ/kg

II. Indirect method (Heat Loss Method)

Here, Boiler efficiency is the difference between heat losses and energy input. This method is initiated by determining the individual losses taking place in a boiler and then deducting the total losses from 100% [5].

Nonetheless, Rakhoh [13] highlighted the advantages of the indirect method to include but not limited to complete balance between mass and energy for individual streams while the disadvantages are too much time is required, need laboratory settings and tools for analysis. On the other hand, the advantages of the direct method are quick evaluation, needs few factors for calculations, and requires fewer instruments for testing while the disadvantages are causes of low efficiency remain unspecified, doses do not calculate various losses at different stages, wet steam due to carryover may lead to incorrect evaporation ration and efficiency.

E. Calculation of Boiler Equivalent Mass, Factor of Evaporation, And Load Factor

III. Equivalent mass and evaporation:

According to Tolga [11], equivalent evaporation is the ratio of total heat energy of generated steam to the latent heat of steam at atmospheric pressure. Thus, equivalent evaporation indicates the evaporative capacity of a boiler per kg of fuel burnt. That is the actual amount of heat added to the boiler to generate steam. Hence, to calculate for the equivalent evaporation, the under-listed formulas were applied as demonstrated by [9] [11].

$$\text{Equivalent evaporation, E} = \frac{\text{me (hsup} - \text{hf1)}}{2257}\ \text{kg/kg of fuel}$$

Where;

me = equivalent mass in Kg/Kg of fuel

h_{sup} = enthalpy of steam in KJ/Kg

h_{f1} = enthalpy of water in KJ/Kg

2257 = latent heat of steam at atmospheric pressure

$$\therefore \text{Equivalent mass, (me)} \frac{\textit{Mass of steam}}{\textit{Mass of fuel}}\ \text{kg/kg of fuel}$$

IV. The factor of Evaporation

Similarly, Tolga [11] stated that the factor of evaporation is the ratio of equivalent evaporation to the actual mass of steam produced.

$$\text{The factor of evaporation, (Fe)} \frac{\text{Equivalent evaporation}}{\text{Actual mass of steam generated}}$$

V. Boiler Load Factor:

Boiler load factor is the ratio of the difference between the feed water flow rate in Kg/h and the boiler blowdown rate in Kg/h to the maximum rated fed water flow rate in Kg/h expressed in percentage. In light of this study, boiler blowdown was ignored during this process.

Therefore, the boiler load factor is;

$$= \frac{\text{Feedwater rate Kg/h} - \text{Boiler blowdown rate Kg/h}}{\text{Maximum rated feedwater flow rate Kg/h}}$$

$$\text{Boiler Load Factor (LF)} = \frac{M_{fw} - M_b}{M_{fwmax}} \times 100$$

Where;

M_{fw} stands for Feedwater mass flow rate in Kg/h
M_b = Boiler blowdown mass flow rate in Kg/h
M_{fwmax} = Maximum rated feedwater mass flow rate in Kg/h

II. METHODOLOGY

This study aims to determine the best boiler efficiency using a direct method based on ASME PTC 4-1 Standard.

A. Data and Calculation

Data collected from each boiler are fuel consumption rate, steam flow rate, steam pressure, steam temperature; economizer outlet feed water temperature, and Gross calorific value of fuel for the analysis.

Table 1: Considered Parameters for Boilers

Parameter	Unit	Boiler #1	Boiler #2	Boiler #4	Boiler #5	Boiler #6
Main steam flow rate	T/H	511.90	632.50	612.9	535.57	617
Main steam pressure	MPa	12.48	12.37	12.46	12.50	12.58
Main steam temperature	^oC	541.40	543.3	539.2	540	539
Enthalpy of superheated steam	KJ/kg	3454.31	3460.45	3448.76	3450.43	3447.81
Temperature of feedwater	^oC	251.40	265	250.0	234.44	260.23
Enthalpy of feed water	KJ/kg	1092.50	1159.81	1085.69	529.3	1135.97
Feedwater flow rate	T/H	509.50	690.3	674.5	1011.12	50253.40
Fuel flow rate	T/H	33.18	42.80	41.47	33.26	35.59
The gross calorific value of fuel	KJ/kg	50253.4	50353.4	50253.40	50253.40	615.3

The calculation for Boiler #-1

$$\text{Boiler Efficiency} = \frac{\text{Heat Output}}{\text{Heat Input}}$$

$$\frac{\text{Steam flow rate x (steam enthalpy} - \text{feed water enthalpy)}}{\text{Fuel firing rate x Gross calorific value of fuel}}\ \text{X 100}$$

$$\text{Boiler Efficiency } (\eta_{boiler}) = \frac{\text{Ms} \times (\text{hsup} - \text{hf1})}{\text{Mf} \times \text{HCV of Gas}} \times 100$$

The calculation for Equivalent mass and Equivalent evaporation

$$\text{Equivalent mass, (me)} \frac{\textit{Mass of steam}}{\textit{Mass of fuel}}\ \text{kg/kg of fuel}$$

$$\text{Equivalent mass, (me)} \frac{511900}{33180}\ \text{kg/kg of fuel}$$

$$\therefore \text{me} = 15.43\text{kg/kg of fuel}$$

Hence, the boiler evaporation ratio is 15.43

Equivalent evaporation (Ee);

$$= \frac{\text{me (hsup} - \text{hf1)}}{2257}\ \text{kg/kg of fuel}$$

$$\frac{15.43\ (3451.31 - 1092.5)}{2257}\ \text{kg/kg of fuel}$$

$$\text{Ee} = \frac{15.43 \times 2358.81}{2257}\ \text{kg/kg of fuel}$$

$$\text{Ee} = \frac{36396.4383}{2257}\ \text{kg/kg of natural gas}$$

$$\therefore \text{Ee} = 16.13\ \text{kg/kg of natural gas}$$

The calculation for the Factor of evaporation

$$= \frac{\text{Equivalent evaporation kg/kg}}{\text{The actual mass of steam generated kg/kg}}$$

$$\text{The factor of evaporation, (Fe)} \frac{16.13}{15.43}$$

$\therefore$ Fe = 1.05

The calculation for the Boiler Load factor

$$\text{Boiler Load factor}(LF) = \frac{M_{fw} - M_b}{M_{fwmax}} \times 100$$

$$Boiler\ Load\ Factor\,(LF)\,\frac{509.5 \times 1000}{695 \times 1000} \times 100$$

$$Boiler\ Load\ Factor\,(LF)\,\frac{509500}{695000} \times 100$$

$\therefore$ LF = 73.31%

The calculation for Boiler #-2

$$\text{Boiler Efficiency}\ (\eta_{boiler}) = \frac{\text{Ms} \times (\text{hsup} - \text{hf1})}{\text{Mf} \times \text{HCV of Gas}} \times 100$$

Boiler Efficiency (η_{boiler})

$$= \frac{632.5 \times 1000\ (3460.45 - 1159.81)}{42.80 \times 1000 \times 50253.40} \times 100$$

$$\text{Boiler Efficiency}\ (\eta_{boiler}) = \frac{632500 \times 2300.64}{2150845520} \times 100$$

$$\text{Boiler Efficiency}\ (\eta_{boiler}) = \frac{1455154800}{2150845520} \times 100$$

$\therefore (\eta_{boiler}) = 67.66\%$

The calculation for Equivalent mass and Equivalent evaporation

$$\text{Equivalent mass, (me)}\ \frac{Mass\ of\ steam}{Mass\ of\ fuel}\text{kg/kg of fuel}$$

$$\text{Equivalent mass, (me)}\ \frac{632500}{42800}\text{ kg/kg of natural gas}$$

$\therefore$ me = 14.78.44 kg/kg of natural gas

Equivalent evaporation (Ee);

$$= \frac{\text{me (hsup} - \text{hf1)}}{2257}\text{kg/kg of fuel}$$

Hence, the boiler evaporation ratio is 14:78

Equivalent evaporation (Ee);

$$= \frac{14.78\ (3460.45 - 1159.81)}{2257}\text{kg/kg of fuel}$$

$$\text{Ee} = \frac{14.78 \times 2300.64}{2257}\text{kg/kg of natural gas}$$

$$\text{Ee} = \frac{34003.46}{2257}\text{ kg/kg of natural gas}$$

$\therefore$ Ee = 15.07 kg/kg of natural gas

The calculation for the Factor of evaporation (Fe)

$$= \frac{Equivalent\ evaporation\ \ kg/kg}{Actual\ mass\ of\ steam\ generated\ \ kg/kg}$$

$$\text{The factor of evaporation, (Fe)}\ \frac{15.07}{14.78}$$

$\therefore$ Fe = 1.02

The calculation for the Boiler Load factor

$$\text{Boiler Load factor}(LF) = \frac{M_{fw} - M_b}{M_{fwmax}} \times 100$$

$$Boiler\ Load\ Factor\,(LF)\,\frac{690.3 \times 1000}{695 \times 1000} \times 100$$

$$Boiler\ Load\ Factor\,(LF)\,\frac{690300}{695000} \times 100$$

$\therefore$ LF = 99.32%

The calculation for Unit-4 Boiler

$$\text{Boiler Efficiency}\ (\eta_{boiler}) = \frac{\text{Ms} \times (\text{hsup} - \text{hf1})}{\text{Mf} \times \text{HCV of Gas}} \times 100$$

$$= \frac{612.9 \times 1000\ (3448.76 - 1085.69)}{41.47 \times 1000 \times 50253.40} \times 100$$

$$\text{Boiler Efficiency}\ (\eta_{boiler}) = \frac{612900 \times 2363.07}{1662382472} \times 100$$

$$\text{Boiler Efficiency}\ (\eta_{boiler}) = \frac{1448325603}{2084008498} \times 100$$

$\therefore (B\eta_{boiler}) = 69.50\%$

The calculation for Equivalent mass and Equivalent evaporation

$$\text{Equivalent mass, (me)}\ \frac{Mass\ of\ steam}{Mass\ of\ fuel}\text{kg/kg of fuel}$$

$$\text{Equivalent mass, (me)}\ \frac{612900}{41470}\text{ kg/kg of natural gas}$$

$\therefore$ me = 14.78 kg/kg of natural gas

Hence, the boiler evaporation ratio is 18.47

Equivalent evaporation (Ee);

$$= \frac{14.78\ (\text{hsup} - \text{hf1})}{2257}\text{kg/kg of fuel}$$

$$= \frac{14.78\ (3448.76 - 1085.69)}{2257}\text{kg/kg of fuel}$$

$$\text{Ee} = \frac{14.78 \times 2363.07}{2257}\text{kg/kg of natural gas}$$

$$\text{Ee} = \frac{43645.9029}{2257}\text{ kg/kg of natural gas}$$

$\therefore$ Ee = 15.47 kg/kg of natural gas

The calculation for the Factor of evaporation (Fe);

$$= \frac{Equivalent\ evaporation\ \ kg/kg}{Actual\ mass\ of\ steam\ generated\ \ kg/kg}$$

$$\text{The factor of evaporation, (Fe)}\ \frac{15.47}{14.78}$$

$\therefore$ Fe = 1.05

The calculation for the Boiler Load factor

$$\text{Boiler Load factor}(LF) = \frac{M_{fw} - M_b}{M_{fwmax}} \times 100$$

$$Boiler\ Load\ Factor\,(LF)\,\frac{674.5 \times 1000}{695 \times 1000} \times 100$$

$$Boiler\ Load\ Factor\,(LF)\,\frac{674500}{695000} \times 100$$

$\therefore$ LF = 97.05%

The calculation for Boiler #-5

$$\text{Boiler Efficiency}\ (\eta_{boiler}) = \frac{\text{Ms} \times (\text{hsup} - \text{hf1})}{\text{Mf} \times \text{HCV of Gas}} \times 100$$

$$= \frac{535.57 \times 1000\ (3450.43\ - 1011.12)}{33.26 \times 1000 \times 50253.40} \times 100$$

$$\text{Boiler Efficiency } (\eta_{boiler}) = \frac{535570\ \times 2439.31}{1671482084} \times 100$$

$$\text{Boiler Efficiency } (\eta_{boiler}) = \frac{1306421256.7}{1671482084} \times 100$$

$$\therefore \eta_{boiler} = 78.16\%$$

The calculation for Equivalent mass and Equivalent evaporation

$$\text{Equivalent mass, (me) } \frac{Mass\ of\ steam}{Mass\ of\ fuel} \text{kg/kg of fuel}$$

$$\text{Equivalent mass, (me) } \frac{535570}{33260} \text{ kg/kg of fuel}$$

$$\therefore \text{me} = 16.101\text{kg /kg of fuel}$$

Equivalent evaporation (Ee);

$$= \frac{\text{me (hsup} - \text{hf1)}}{2257} \text{kg/kg of fuel}$$

$$\text{Ee} = \frac{16.10\ (3450.43\ - 1011.12)}{2257} \text{kg/kg of fuel}$$

$$\text{Ee} = \frac{16.10\ \times 2439.31}{2257} \text{kg/kg of fuel}$$

$$\text{Ee} = \frac{39272.891}{2257} \text{kg/kg of natural gas}$$

$$\therefore \text{E} = 17.40 \text{ kg/kg of natural gas}$$

The calculation for the Factor of evaporation (Fe);

$$= \frac{\text{Equivalent evaporation kg/kg}}{\text{Actual mass of steam generated kg/kg}}$$

$$\text{The factor of evaporation, (Fe) } \frac{17.40}{16.10}$$

$$\therefore \text{Fe} = 1.08$$

The calculation for the Boiler Load factor

$$\text{Boiler Load factor}(LF) = \frac{M_{fw}\ - M_b}{M_{fwmax}} \times 100$$

$$Boiler\ Load\ Factor\ (LF) \frac{529.3 \times 1000}{695 \times 1000} \times 100$$

$$Boiler\ Load\ Factor\ (LF) \frac{529300}{695000} \times 100$$

$$\therefore \text{LF} = 76.16\%$$

The calculation for Boiler #-6

$$\text{Boiler Efficiency } (\eta_{boiler}) = \frac{\text{Ms} \times \text{(hsup} - \text{hf1)}}{\text{Mf} \times \text{HCV of Gas}} \times 100$$

$$= \frac{617 \times 1000\ (3447.81 - 1135.97)}{35.59 \times 1000\ \times 50253.40} \times 100$$

$$\text{Boiler Efficiency } (\eta_{boiler}) = \frac{617000 \times 2311.21}{1788518506} \times 100$$

$$\text{Boiler Efficiency } (\eta_{boiler}) = \frac{1426016570}{1788518506} \times 100$$

$$\therefore \eta_{boiler} = 79.73\%$$

The calculation for Equivalent mass and Equivalent evaporation

$$\text{Equivalent mass, (me) } \frac{Mass\ of\ steam}{Mass\ of\ fuel} \text{kg/kg of fuel}$$

$$\text{Equivalent mass, (me) } \frac{617000}{35590} \text{ kg/kg of fuel}$$

$$\therefore \text{me} = 17.34\text{kg/kg of fuel}$$

Equivalent evaporation (Ee);

$$= \frac{\text{me (hsup} - \text{hf1)}}{2257} \text{kg/kg of fuel}$$

$$= \frac{17.34\ (3447.81 - 1135.97)}{2257} \text{kg/kg of fuel}$$

$$\text{Ee} = \frac{17.34\ \times 2311.21}{2257} \text{kg/kg of fuel}$$

$$\text{Ee} = \frac{40076.3814}{2257} \text{kg/kg of natural gas}$$

$$\therefore \text{E} = 17.76 \text{ kg/kg of natural gas}$$

$$\text{Boiler Load factor}(LF) = \frac{M_{fw}\ - M_b}{M_{fwmax}} \times 100$$

$$Boiler\ Load\ Factor\ (LF) \frac{615.3 \times 1000}{695 \times 1000} \times 100$$

$$Boiler\ Load\ Factor\ (LF) \frac{615300}{695000} \times 100$$

$$\therefore \text{LF} = 88.53\%$$

III. RESULTS AND DISCUSSION

Table 2: Performance Balance Sheet for Boilers

Parameters	Boiler# 1	Boiler# 2	Boiler# 4	Boiler# 5	Boiler# 6
Boiler Efficiency (%)	72.51	67.66	69.50	78.16	79.73
Boiler Evaporation Ratio	15.43	14.78	14.78	16.10	17.34
Boiler Equivalent Evaporation (kg/kg)	16.13	15.07	15.47	17.40	17.76
Boiler Factor of Evaporation	1.05	1.02	1.05	1.08	1.02
Boiler Load Factor (%)	73.31	99.32	97.05	76.16	88.53

From the findings presented in table 2, the boiler evaporation ratio shows that Ikg of natural gas is required by Boiler# -1 to generate 16.13kg of steam with an efficiency of 72.51%. Similarly, the load factor of 73.31% indicates that boiler#-1 can generate about 73.31% of its installed/rated steam generation capacity. Likewise, Ikg of natural gas is required by Boiler#-2 to generate 15.07kg of steam with fuel-to-steam efficiency of 67.66% and a load factor of 99.32% and a factor of evaporation of 1.02. Again, Boiler#-4 fuel-to-steam efficiency is 69.50% and generates

15.47kg of steam by 1kg of Fuel burnt yielding a 97.05% load factor and 1.05 factor of evaporation. Boiler #-5 has a fuel-to-steam efficiency of 78.16% by evaporating 17.40kg of steam when 1kg of fuel was burnt and has a load factor of 76.16% and 1.08 factor of evaporation. While Boiler #-6 has fuel-to-steam efficiency of 79.73% and a load factor of 88.53% and 1.02 factor of evaporation when 1kg of fuel was burnt to generate 17.76kg of steam. Furthermore, boiler efficiency could be improved by proper balancing of air/fuel ratio, adequate maintenance, and real-time monitoring of the steam to fuel ratio. More so, boiler efficiency is critical to knowing the performance of a boiler and fuel to steam ratio visa vice its water consumption. Finally, the fuel-to-steam efficiencies of the various boilers studied show little deviation from the installed value, which is 85%.

IV. CONCLUSION

The importance of boiler efficiency to its performance cannot be over-emphasized. Standards and methods for calculating boiler efficiencies were deliberated with their mathematical expressions. The high values of fuel-to-steam efficiencies of the boilers studied are the consequences of proper preventive maintenance and strike adherence to standard operating procedures.

Finally, with this succinct evaluation of these boilers' efficiencies, Technicians and Engineers as well as managers alike can now make strategic decisions regarding the performance of individual boilers. However, more study is required to investigate heat losses to apply the indirect method to find the efficiency of the various boilers.

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