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Calculating the Efficiency of Steam Boilers Based on Its Most Effecting Factors: A Case Study

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Abstract**—**This paper is concerned with calculating boiler efficiency as one of the most important types of performance measurements in any steam power plant. That has a key role in determining the overall effectiveness of the whole system within the power station. For this calculation, a Visual-Basic program was developed, and a steam power plant known as El-Khmus power plant, Libya was selected as a case study. The calculation of the boiler efficiency was applied by using heating balance method. The findings showed how the maximum heat energy which produced from the boiler increases the boiler efficiency through increasing the temperature of the feed water, and decreasing the exhaust temperature along with humidity levels of the of fuel used within the boiler.

Keywords**—**Boiler, Calculation, Efficiency, Performance. Steam

I. Introduction

THIS recent era complied many areas of research and industry to work towards improving their operations. Among of these operations are developing the electric energy operations which indeed play a key role for updating and improving this area of industry and research. In general, many methods are well-known and being used within this area for producing the electric energy, among of them is using steam generation stations. Boilers are considered to be as the key part in any generation station as it is the place where the fuel is used for producing the needed amount of heat [1]. This fact arises the importance of knowing the efficiency levels of the boilers within any electrical generation station. The efficiency levels of the boiler can be known as the percentage between the used amount of heat to generate the steam and the amount of heat produced by burning of the used fuel [1], [2].In general, there are many methods being used for calculating the boiler efficiency levels, direct methods, indirect ones, and a method known as heating balance. For this research, the heating balance method was the selected method to be used for the required calculations as it provides a general insight for the changes of the heating energy levels in the boiler, making these calculations much more clear and easy to present.

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The heating balance method (used for calculating the boiler efficiency) is considered as the most important method in many calculations of boilers efficiency [3], [4]. The heating balance of boilers is usually limited by the maximum thermal value of fuel (HHV) which includes six parts. One of them is absorbing energy water, whereas the other five parts represents indicators related to the boilers, usually due to incomplete burning, and increasing the temperature of let-out gaze [2], [5].

II. Common Energy Losses In Heating Balance Method

The common losses in energy while using the heating balance method are cited as below [2]:

- Energy absorbed by water feed, expressed mathematically as E1=[Ms(hs-hw)+Mrh(hro-hri)]/mf
- Loss energy in dry exhaust gases, expressed as E2 = [Mg. Cpg (Tg- Ta)]/Mf
- Loss of energy in exhaust gases due to humidity level in fuel, as E3=Mw[Cpw (100-Ta) +2285+ Cpfuel(Tg-100)]
- Loss of energy attributed to incomplete combustion (CO), expressed as E4= (Pwco/Pwgass) . Mg. Cvco
- Loss from rays and uncountable loss, expressed as E5 = Ef -∑ Ei
- Loss of energy in exhaust gases attributed to the water vapor for med by combustion of the hydrogen in the fuel which can be expressed as $2H_2 + O_2 \rightarrow 2H_2O$

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III. Experimental Study

The experimental study took place at El-Khmus Steam Power Plant, Libya, and will be concerned on the changes of the boiler efficiency levels, along with the effect of different factors that can be changed in the boiler such as temperature of water feed , temperature of exhaust gases, level of humidity in

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the fuel. A computer program (visual basic) was developed for this purpose to calculate the changes in the efficiency levels of the boiler. Table I presents some constants being used to run the developed computer program [4], [7]. Whereas, Table II, shows the readings that being taken as the maximum load being used within the steam power plant [3], [6].

TABLE I
CONSTANTS NEEDED TO RUN THE COMPUTER PROGRAM

Type of Constant	Symbol	Constant
Enthalpy of steam outlet of boiler	hs	3445 KJ/KG
Enthalpy of steam inlet to reheat	hri	3075 KJ/KG
Enthalpy of steam outlet of reheat	hro	3555 KJ/KG
Enthalpy of feed water	hw	999.12 KJ/KG

TABLE II
READINGS FROM EL-KHUMS STEAM POWER PLANT

Parameter	**Symbol**	**Value(Unit)**
Temperature of feed in inlet economizer	Tw	230 C°
Mass flow feed water ratio	mw	375000 Kg/hr
The mass of the used fuel	mf	29264.75 Kg/hr
Flow ratio of steam outlet of super heater	Ms	351300 Kg/hr
Specific heat of fuel	Cp.f	2.3 KJ/Kg.K°
Thermal value of fuel	HHV	40200 KJ/Kg
Humidity level in fuel	Mw	3.3%
Mass of combustion gases per kg/fuel	Mg	14.21 Kg/Kgfuel
Average temp. for exhaust gases	Tg	165 C°
Average temperature for air surrounding the boiler	Ta	25 C°
Specific heat for exhaust gases	Cpg	1.0893 KJ/Kg.K°
Flow ratio of steam outlet of reheat	Mrh	300000 Kg/hr
Temp. of steam outlet of superheat	Ts	540 C°
Temperature of steam outlet of reheat	Tro	540 C°
Temperature of steam inlet to reheat	Tri	330 C°
Pressure of steam outlet of reheat	Pso	28.1 bar
Pressure of steam upon out of boiler	Pro	131 bar
Quality of thermal capacity water	Cpw	4.18 KJ/Kg.K°
Quality of thermal capacity to air	Cpa	1.005 KJ/Kg.K°

IV. RESULTS AND DISCUSSION

Key results are shown in Table III, values of EF % , ET, EE1 , E1 and hw all being taken and being presented the changes of the temperature of feed water (Tw), enthalpy to feed water (hw), The quantity of thermal energy (E1), The value of thermal gain energy (thermal acquirement energy) (EE1), the value of total thermal energy that used in the steam boiler (ET), and thermal specific to the boiler (EF%).

TABLE III
VALUE OF (EF% , ET , EE1 , E1 , HW) WITH TEMPERATURE CHANGE TO THE FEED WATER (TW)

Tw C°	Hw KJ/Kg	E1 KJ/Kg	EE1 KJ/Kg	ET KJ/Kg	EF%
230	990.12	37218.98	0.0234375	37219.02	0.9258463
235	1013.62	36917.84	301.1563	37520.16	0.9333372
240	1037.32	36614.15	604.8477	37823.85	0.9408917
245	1061.23	36307.77	911.2305	38130.23	0.9485132
250	1085.36	35998.57	1220.434	38439.43	0.9562048
255	1109.73	35686.29	1532.715	38751.71	0.963973
260	1134.37	35370.55	1848.453	39067.45	0.9718272

The change of the thermal energy loses along with the values of thermal gains when decreasing the temperature of the exhaust gases are all shown in Table IV, whereas the changes of E3, EE3, ET, and EF% with changing the humidity value (W) are all shown in Table V.

TABLE IV
VALUES OF (E2, EE2, ET, AND EF%) WITH TEMPERATURE OF EXHAUST GASES

T g	E2 KJ/Kg	EE2 KJ/Kg	ET KJ/Kg	EF%
160	2167.053	-4.49992	37219	0.9258457
155	2089.659	77.77143	37296.77	0.9277803
150	2010.264	155.5474	37374.55	0.9297151
145	1934.869	233.3233	37452.32	0.9316490
140	1857.474	311.0992	37530.1	0.9335845
135	1780.08	388.8751	37607.88	0.9355193
130	1702.685	466.651	37685.65	0.937454

TABLE V
SHOWS THE VALUES OF E3, EE3, ET, AND EF% WITH CHANGING THE HUMIDITY (W)

W	E3	EE3	ET	EF %
0.032	87.0928	2.717196	37221.72	0.9259134
0.031	84.37115	5.438853	37224.44	0.9259810
0.03	18.6495	8.160502	37227.16	0.9260488
0.029	87.92785	10.88215	37229.88	0.9261165
0.028	67.2062	13.6038	37232.61	0.9261842
0.027	37.48455	16.32545	37253.32	0.9262518
0.026	70.7629	19.0471	37238.05	0.9263196

To discuss these findings, Figures from 1 to 5, represents the changes realized due to changing the temperature of the feed water. The temperature of output exhaust gases, the fuel humidity levels are all clearly shown on the same figures. The figures also show how the factors affect these changes due to the thermal gain (EE) along with the efficiency of the boiler (EF%).

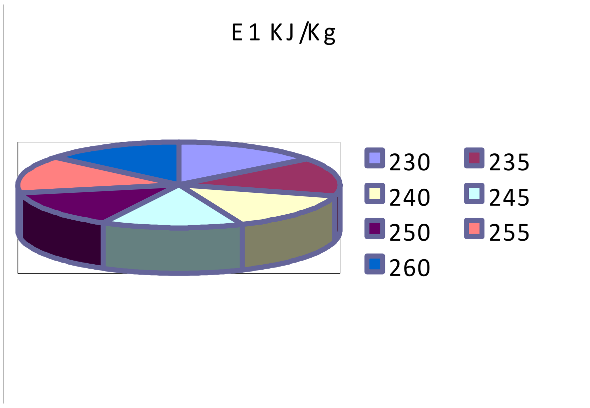

Fig. 1 effect of temperature of the feed water (Tw C°) on E1,EE1,ET

When discussing Figure 1, the increase in the temperature of feed water (Tw), a decrease of the value of thermal energy can be seen with the change of the feed water to the superheat steam (E1). The thermal gain (EE1) will be increased (see Table III). When E1 decreases, EE1 will increase. The value of 37219 represents the value of the energy supplied to the feed water when (Tw)=230 Cº, and consequently the value of the total thermal energy that used in steam boiler (ET)will increase too .

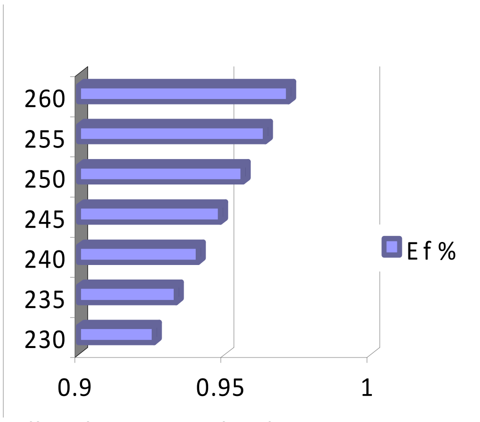

Fig. 2 effect of temperature of the feed water (Tw C°) on EF%

Figure 2, shows increasing values of efficiency levels (ET) of the boiler with increasing of Tw, whereas Figure III represents the change of ET, EE2, E2 values with decreasing the temperature of the exhaust gases. It shows that when the temperature of exhaust gases around the surrounding area increases, the lost of thermal energy will increase as well, and vice versa. A decrease in E2 values was noticed with the exhaust gases, means an increases in EE2 (thermal gain energy) and increases in ET (the total thermal energy).

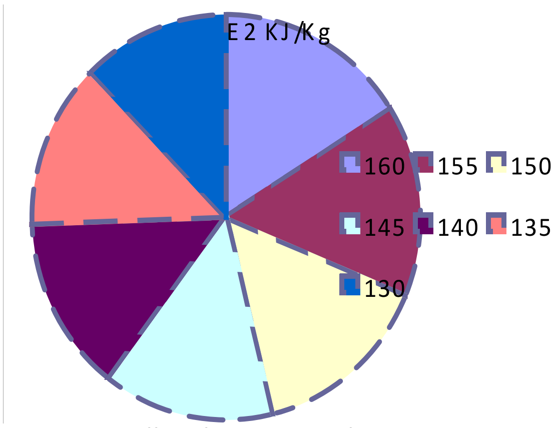

Fig. 3 shows the effect of temperatures of exhaust gases (Tg C°) on E2, EE2, ET

Figure 4, represents the effect of the temperature of exhaust gases on the efficiency of boiler, whereas Figure V, points to the changes being realized to ET, EE3, E3 with humidity levels of the used fuel.

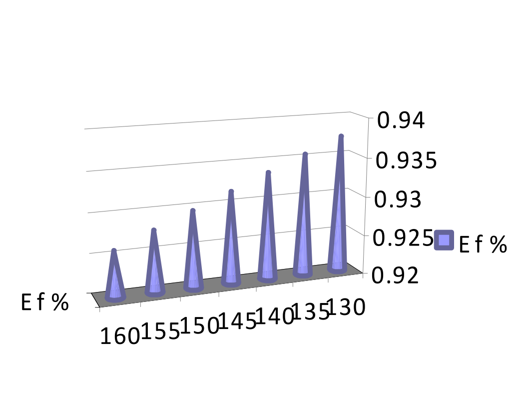

Fig. 4, shows the effect of exhaust gases temperature (Tg C°) on EF

Table IV, also shows that when the level of humidity is 3.3%, it can be seen that E3=87.0928KJ/Kg, EE=2.717196KJ/Kg, showing that if the humidity decreases to 2.6%, E3 decreases to 70.7629KJ/Kg. EE3 is also increases to19.0471KJ/Kg and ET increases as well. According to the design standards, it can be noticed that increasing the value of ET can be seen when increasing the temperature of the feed water due to decreases in exhaust gases as shown on Figure 5.

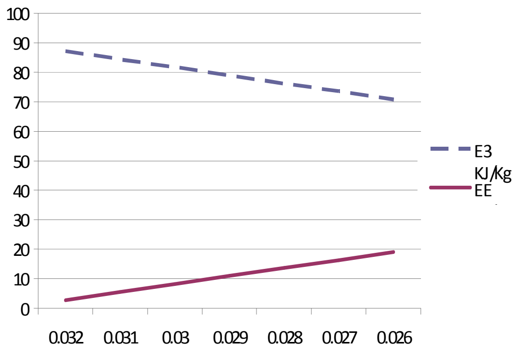

Fig. 5 shows the effect of W% on E3, EE3

V. CONCLUSIONS

The findings of this research clearly show the changes of efficiency levels that related to the steam boilers. The efficiency levels were based on the changes of the temperature of the used feed water for the boilers along with the changes of the temperature of the exhaust gases. The humidity levels of the used fuel within the boiler are also being considered. This research has also indicated that the efficiency of the steam power plant will increase and showing higher level of effectiveness when applying good and more reliable working conditions.

Herewith, some recommendation points:

- An economical and more detailed feasibility studies should be conducted to arise the potential benefits of increasing the efficiency of the boilers and heat ness
- Conducting an investigation studies for other steam power plants within the same area, and then after making comparisons between both findings in order to be more aware of all the working conditions and environments within more power plants.
- Future studies may include some more effective factors that affecting the boiler efficiency such as boiler pressure and input air to the fuel room.
- Future studies should also include quality factors of the used fuel within the steam power plants in order to improve the efficiency of the boilers within the electrical power stations.

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