Computer-Based Boiler Efficiency Improvement, Studying the Most Effective Parameters: A Case Study

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Abstract

This paper is concerned with how energy saving in steam boiler system. The simple mathematical model of a steam boiler has been developed for calculating boiler efficiency by using java web application. The Model shows the influence of the most effective parameters on the boiler performance and its applications in two types of boilers (water and fire tube boilers). The findings showed, in the case of a water tube boiler when natural gas fuel used, every 10% in the excess air causing decreasing boiler efficiency by 0.37%. Also every 10% (20◦C) increase in temperature of flue gases causing decreasing in boiler efficiency by 1 %, and every 10% (7-8)◦C increase in feed water temperature causing increasing in boiler efficiency by 1%,, In case of fire tube boiler when liquid fuel (solar) used, every 10% increase in the excess air causing decreasing in boiler efficiency by 5%, every 10 %(20◦C) increase in temperature of flue gases causing decreasing in boiler efficiency by 1-2%, The model gave acceptable agreement with experimental data measured, in addition, the model has economic and environmental effect.
Keywords: Boiler Efficiency, Parameters, Java Web Application, Steam Boilers

I. INTRODUCTION

Boilers are the key part in any power station as it is the place where the fuel is used for producing the needed amount of heat in the form of steam. Facing enormous demand for electricity and growing need for more and safer power generating has motivated investigation into the dynamic analysis of power plants to design more reliable control systems with saving cost, keeping better system performance which means an increase in power generation efficiency and also decrease in the maintenance costs, also remembering the value of steam boiler system, so maintaining it properly to save cost in future.

studying the effective parameter that affects on boiler performance, making us taking right decision at the right time to control steam boiler efficiency, with traditional methods; operators often are not able to detect the critical condition to achieve high performance, as steam boiler considered hazard system because it works at high pressure and temperature, so we use mathematical model to help us to control the performance of steam boiler with safety method. Many models found in the market very effective but it is very high-priced, in our energy saving study, we developed a simple mathematical model with Java web application language with high accuracy to calculate boiler efficiency and combustion products then we used this model for studying the effect of excess air, the temperature of flue gases and the temperature of feed water on the two types of the steam boiler using a different type of fuels.

There were many studies developed to study the effect of these parameters on boiler performance by using various types of model, like, Gopinath 2014 [1], used Artificial Neural Network (ANN) for prediction the optimize excess air for improving boiler efficiency, he said that "The Excess air requirement predicted by the ANN is in good understanding with the values using indirect method. As the CO2 actual from the flue gas reduces, the excess air Requirement is increasing". Che in 2004 [2], found that, a gas-fired boiler thermal efficiency could be improved from 16.8% to 15.1% when the flue gas temperature is reduced to 25–35◦C. as follow, the dust, NOx, SOx, and soot of the flue gas components can be partially, may be totally, dissolved in the water condensation, so that the pollutants emitted by the boilers can be exactly reduced. Nabil M. Muhaisen, Rajab Abdullah Hokoma 2012 [3], studied the effect of increasing feed water temperature and decreasing the flue gas temperature on increasing boiler efficiency. He found that" The efficiency levels were based on the changes in the temperature of the used feed water for the boilers along with the changes in the temperature of the exhaust gases". Kouprianov in 2003 [4], studies The effect of excess air on emissions (NOx, SO2 and CO) on a 150 MW boiler firing the study said that " The NOx emissions were found to increase with the higher excess air ratios; the NOx values in the flue gas (at 6% O2) ranged from 257 to 325 ppm, whilst the excess air ratio varied from 1.06 to 1.32 at the economizer outlet. MA Rosen in 2008 [5], improved steam power plant efficiency through exergy analysis by decreasing the fraction of excess combustion air, and/or the stack-gas temperature, he said" Overall-plant energy and exergy efficiencies both increase by 1.4% when the fraction of excess combustion air decreases from 0.4 to 0.15, and by 3.5% when the stack-gas temperature decreases from 149◦C to 87◦C. When both decreases occur, both plant energy and exergy efficiencies increase by 4.1%". Bhaskaran in 2016 [6], studied the effect of Feedwater and the Flue gas temperatures for different types of fuels such as Coal, furnace oil and bagasse he found that, 20% rise in feed water temperature led to reduction in the total loss of 1% and an increase in the efficiency of the boiler by 0.55% when coal is used as fuel In the case of furnace oil, the reduction in the total loss was 0.5% with an increase in boiler efficiency of about 0.3%. Likewise, in the case of bagasse, the reduction in total loss was 1.5% with an increase in 1.2% of boiler efficiency, and 10.5% decrease in flue gas temperature, there is the reduction of total loss of 2.12% and 1.31% increase in boiler efficiency when coal was used as fuel. In the case of furnace oil, the reduction in the total loss was 1.5% with an increase in boiler efficiency of about 0.85%. Likewise, in the case of bagasse, the reduction in total loss was 2.86% with an increase in 2.2% of boiler efficiency. recently a new modification in conventional mathematical formulation of efficiency is presented by Ahamed Rehan in 2018 [7], based on time-varying efficiency using time-varying operational variables of boiler, in this model, he discussed the influence of variations in air to fuel ratio and fuel flow rate upon efficiency the study showed that time-varying efficiency covers a deeper aspect of the dynamic relation between efficiency and other input of boiler especially air to fuel ratio and fuel flow rate.

From the previous we found that, Feed water and the Flue gas temperatures, and percentage of excess air are the important parameters that improve the efficiency of the boiler, that clarifies the value of measuring them accurately in the steam boiler system, therefore by applying our suggested simple mathematical model specialized for steam boiler we could measure the critical limits which get high efficiency of steam boiler and explaining them on the graphs. We used for calculating the boiler efficiency two methods (direct and indirect method) which help us knowing percentages of losses in the boiler.

Our target is defining the critical limits for these parameters having effects on any steam boiler performance.

II. EXPERIMENTAL STUDY

The data used from water tube boiler using natural gas fuel and fire tube boiler using liquid fuel (solar) from a Salt production company.

Table (1) shows specifications of the water tube boiler and the readings that were taken as the maximum load within the boiler. Table (2) presents some constants being used to run the developed computer program.

Table – 1
Readings from water tube boiler

Company name Site place Department: Date of measure: Model: Manufacture	EMI sale Company for salt production Egypt Steam turbine department. 10/2/2017 32/5216 British,1998	
parameter	*symbol*	*Value(unit)*
The temperature of the feed water	T_w	135°C
Mass flow feed water ratio	M_w	$35m^3/hr$
The mass of the used fuel	M_f	$3000m^3/hr$
Average temp. for exhaust gases	T_{FG}	215°C
The average temperature for air surrounding the boiler	T_a	27°C
The flow rate of combustion air	M_{air}	$33000m^3/hr$
The flow rate of steam	M_b	35ton/hr.
TDS in the feed water	C_{bd}	50 ppm
TDS in blow down	A_{bd}	700ppm
Temperature of combustion air	T_{air}	50°C

Table – 2
Constants needed to run The Computer program

Type of constant	*symbol*	*constant*
The heat reaction of CO	B	32
constant of dry gas loss	K	0.34
Specific heat of the feed water	C_{MW}	4.186 K j/K g.°c
Specific heat of the fuel	C_{of}	$2.16\ K\ j/m^3\ .°c$
Specific heat of air	C_P	$0.3106\ K\ j/m^3\ .°c$

Table (3) shows the specifications of the fire tube boiler and the readings that were taken as the maximum load within the boiler. Table (4) presents some constants being used to run the developed computer program.

Table – 3
Readings from (Fire tube boiler)

Company name Site place Department: Date of measure: Model: Manufacture	Emisal Company for salt production shakshok, EL-fayom Magnesium department. 18/2/2017 Dennis Baldwin and sons British,2003	
parameter	*symbol*	*Value(unit)*
The Temperature of feed water	T_w	20°C

Mass flow feed water ratio	M_w	300Kg/hr.
The mass of the used fuel	M_f	216Kg/hr.
Average temp. for exhaust gases	T_{FG}	171°C
The average temperature for air surrounding the boiler	T_a	27°C
The flow rate of combustion air	M_{air}	2769.1m^3/hr
The flow rate of steam	M_b	3000Kg/hr.
TDS in the feed water	C_{bd}	100 ppm
TDS in blow down	A_{bd}	3500ppm
Temperature of combustion air	T_{air}	20°C

Table – 4
Constants needed to run the computer program

Type of constant	symbol	Constant
The heat reaction of CO	B	48
constant of dry gas loss	K	0.56
Specific heat of water	C_{MW}	4.186 K j/K g.°c
Specific heat of the fuel	C_{mf}	0.47 K j/m^3 .°c
Specific heat of air	Cp	0.3106 K j/m^3 .°c

III. RESULTS AND DISCUSSION:

A. *Effect of Excess Air on the Water Tube Boiler Efficiency*

The excess air has a direct effect on the losses of dry flue gas (L dg %) Consequently on the combustion efficiency and the boiler efficiency.

The program was used to calculate the boiler efficiency for different values of excess air between zero and 200% with a 5% step. The result of calculations is plotted by using "EXCEL" program, which also used to calculate the regression equation for the curve.

Fig.1 shows the effect of changing the values of excess air on the losses of dry flue gases.

Fig.2 shows the effect of excess air on the combustion efficiency and boiler efficiency. From which it is clear that the increase of excess air increases the dry flue gases losses. To discuss this result:-

The relation between the excess air and loss in dry gases can be expressed by the following regression equation:

$$L_{dg} = 0.0386\, A_{exc.} + 3.9343 \quad \text{Eq. [1]}$$

Where:

L_{dg} : loss of dry flue gases, %

$A_{exc.}$: Excess air, %

From the last equation, it is clear that the increase of the excess air by 10% causing an increase in L_{dg} by 0.347%. Fig.2 shows the relation between excess air and combustion efficiency & boiler efficiency percentage. This relation will have the following forms:

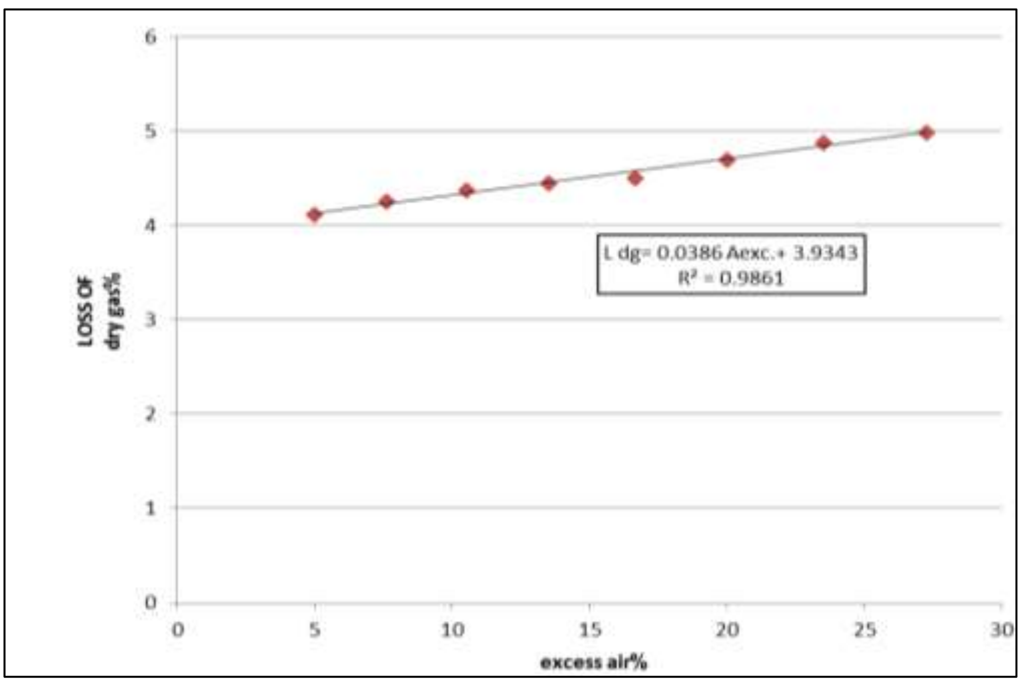

Fig. 1: Relation between excess air% and loss of dry flue gases%

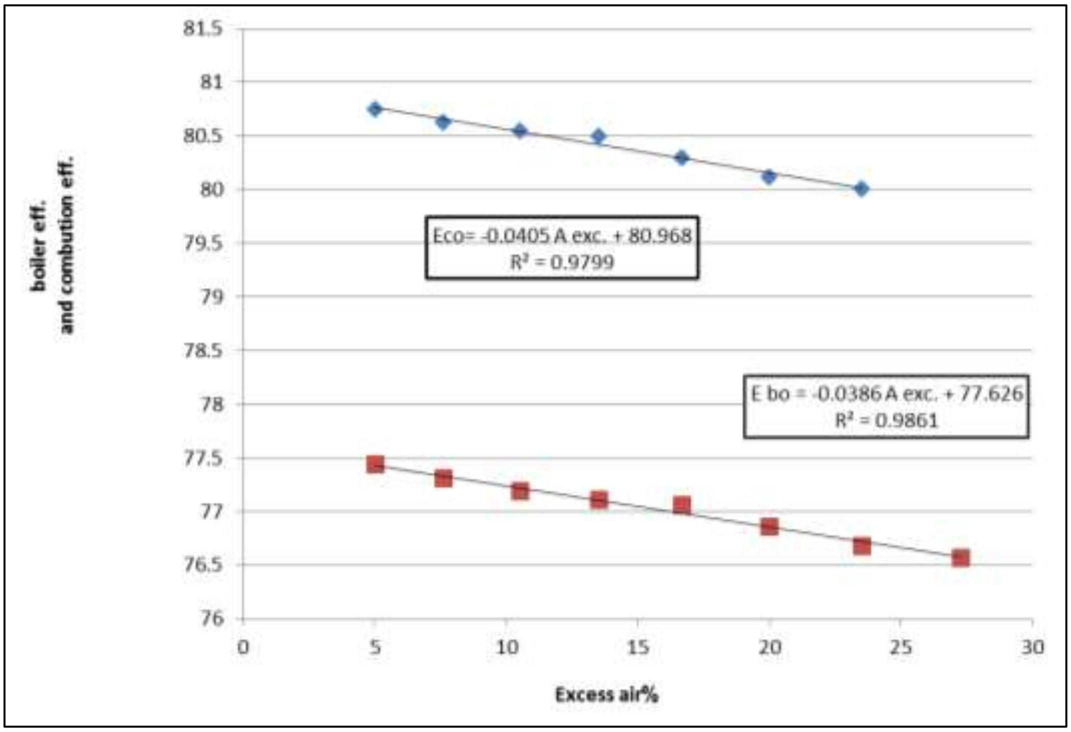

Fig. 2: The relation between excess air% with boiler &combustion efficiency.

$$E_{co} = -0.0405\, A_{exc.} + 80.968 \quad \text{Eq. [2]}$$
$$E_{bo} = -0.0386\, A_{exc.} + 77.626 \quad \text{Eq. [3]}$$

Where:
E_{co}: combustion efficiency, %
E_{bo}: boiler efficiency, %

Excess air has a significant effect on the dry flue gases loss as the doubling of this coefficient from 20%to 40% increases this loss by 16.40%.this, in turn, decrease both of combustion and boiler efficiency as seen in fig.2 this last relation does not take into account the effect of the excess air increase on the inverse of flue gases temperature as the heat transfer coefficient inside the boiler chamber significantly decreases. It means that an increase in excess air coefficient will have a double worse effect on boiler efficiency.

B. Effect of the Temperature of Flue Gases

Fig.3 illustrates that the temperature of flue gases cannot be less than 27°C as an ambient temperature otherwise L_{dg} will take a negative value. Also, it is quite clear that there is a great difference between L_{H2O} and L_{dg} this is because the fuel used contains a considerable amount of hydrogen. As the temperature of flue gases increase both L_{H2O} and L_{dg} increase also, the logic result is the reduction of both combustion and boiler efficiencies as seen in fig.4 the gap between these two losses represents boiler structure and blow down losses .this gap is always constant and equals 2.777%. This loss can be conserved and controlled introducing the recent techniques of energy saving.

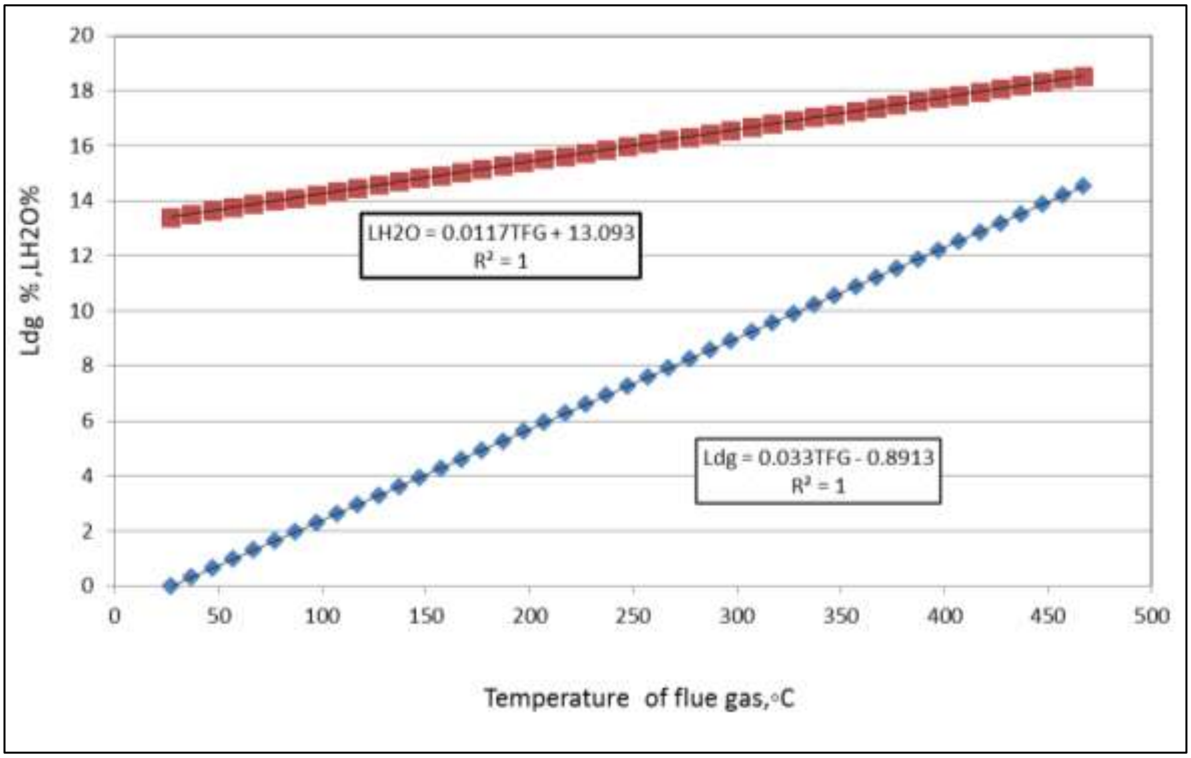

Fig. 3: The relation between the temperature of flue gases and losses of (L_{dg}& L_{H2O})

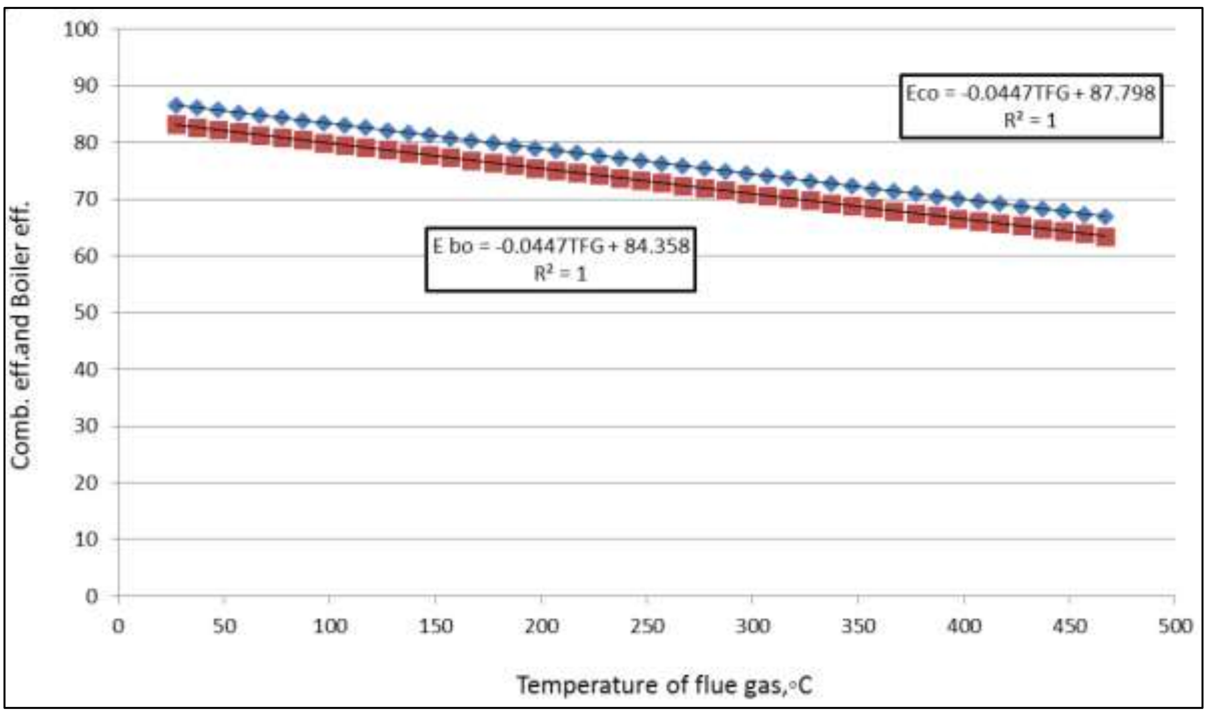

Fig. 4: Relation between temperature of flue gases with combustion and boiler efficiencies

Fig. 5 shows the effect of the temperature of feed water on fuel saving. The result shows, every increase in feed water temperature by (7-8˚C) causing increasing in the boiler efficiency by 1%, and fuel saving will increase by 1% also.

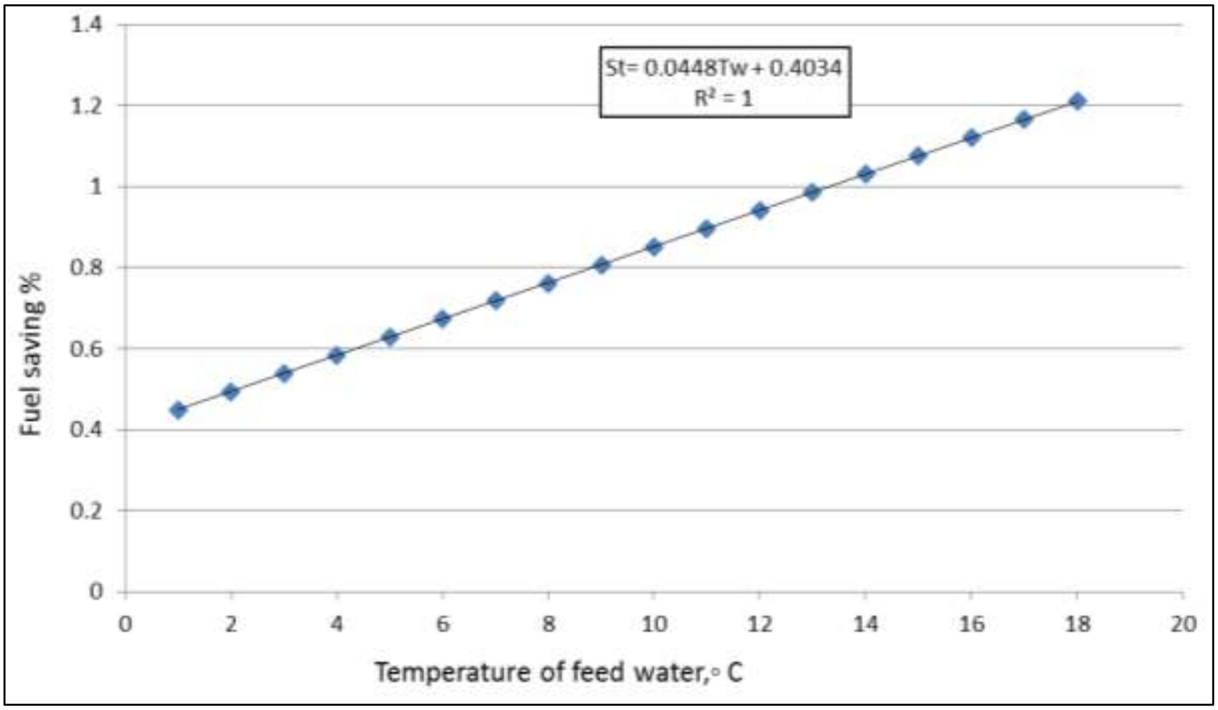

Fig. 5: The relation between preheated feed water and fuel saving

IV. CONCLUSION

The findings of this research show, for water tube boiler, every 10% in the excess air causing decreasing in boiler efficiency by 0.37%. Also every 10% (20˚C) increase in temperature of flue gases causing decreasing in boiler efficiency by 1% ,and every 10% (7-8)˚C increase in feed water temperature causing increasing in boiler efficiency by 1%, for fire tube boiler, every 10% in excess air causing decreasing in boiler efficiency by 0.5%. Also, every 10% (20˚C) increase in temperature of flue gases causing decreasing in boiler efficiency by 1.2%, and every 10% (7-8) ˚C increase in feed water temperature causing increasing in boiler efficiency by 1%, the model shows a good agreement with efficiency calculated from experimental data.

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