Devise Simplified Equation to Calculate the Percentage of Heat Loss with Exhaust Gases, and to Calculate the Coefficient of the Overall Efficiency of the Boiler that Burns Heavy Fuel Oil

Salah Salem Ali
Efficiency And Test Senior Engineer, Al-HISWA Thermal Power Station -Aden
Email: ssa8027@gmail.com

***Abstract*—This paper had come as a result of practical demand that is finding simple and quick solution formula, with great accuracy to count the heat loss with exhaust gases (q_2) in the boiler, and also count the total efficiency (η_g) of the boiler, so that it to be facilitated the specialist researcher to find out (η_g) immediately without going to the long equations. The research methods depended on reducing from the unknown values, and on reducing the modulus basis of nearest fixed values. The main characteristic of the extracted equation to find out the heat loss with exhaust gases (q_2) is that it has 3 unknown values and one constant only. The extracted equation had been tested and compare its results with the reference test after installation the boiler of AL-HISWA POWER STATION by the manufacturing authority by hand account method, or and also with the tests after the over haul maintenance which had been done by computer program. And the comparison results were excellent, so that the error rate in finding out q_2 is (-1.91 % max only one time, and maximum error rate of finding out (η_g) is (-0.1%), and sometimes the error for q_2 & η_g was zero.**

***Index Terms*—boiler, efficiency, heat, losses, gases, air**

I. Symbols And Measurement Units

Q_{use} - amount of heat utilized to convert boiler water into steam, kj / kg.

Q_F - total amount of heat energy given to boiler, kj / kg.

η_g - boiler overall efficiency factor,%

q_2 - percentage of heat loss with the exhaust gases,%

q_3 - percentage of heat loss with non-complete combustion of fuel,%.

q_4 - percentage of heat loss with mechanical no combustion,%

q_5 – percentage of heat loss in the atmosphere around boiler,%

q_6 – percentage of heat loss with slag,%

D_n - boiler par productivity, t / h

D_a - actual productivity of the boiler, t / h

Q_{loss} - the total amount of heat loses, kj / kg

Q_{air} - amount of heat energy entering the boiler with cold air, kj / kg.

Q_G - the amount of heat energy emerging with exhaust gases, kj / kg.

Q_g - the amount of heat loses with exhaust gases, kj / kg.

Q_a - amount of heat energy lost in the atmosphere around boiler, kj / kg.

t_{fg} - exhaust gases temperature outlet the boiler, C^O

t_{ca} - cold air temperature inlet the boiler, C^O

V_g - actual volume of the exhaust gases per 1 kg fuel, m3

V_a -Theoretical volume of air required for combustion 1kg fuel, m3 / kg.

α_{fg} - coefficient of increased air in the exhaust gases,-.

II. Introduction

If we consider that the steam boiler is a device that converts chemical energy of fuel into heat energy which absorbed by the water to turn into steam. So as any energy convertor device, the final result of its work is a useful energy and lost (not utilized) energy. Knowing ratio useful energy to the total energy given can determine the overall efficiency of the work of this device directly without having to calculate the heat losses. So this

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METHOD IS called DIRECT METHOD FOR calculating efficiency. Can also find the overall efficiency of the work of this device by calculating the heat losses as percentages and subtracted them from the full percentage (100%) we obtain on the overall efficiency of the device, this method is called indirect method .

For the boilers to find overall efficiency factor by both mentioned methods as follows:

First - direct method (used to find η_g during long period of time such as a month or season etc. ...)- If useful thermal energy in the boiler which turns the water into steam is Q_{use} , and the amount of heat energy given are Q_F (with fuel and hot air and steam spraying , etc.) so η_g can determined as [1].:

$$\eta_g = 100 Q_{use} / Q_F \tag{1}$$

Second-indirect method (uses during the tests, and features accuracy compared to the direct method): If the total amount of the common thermal losses of the boiler is $\sum q_i$, (percentages), the η_g can be found as follows:

$$\eta_g = 100 - \Sigma q_i \tag{2}$$

The common thermal losses of the boiler, according to some scientific sources are [1]:

- Heat loss with the exhaust gases, and has the symbol q_2 ,%
- Heat loss with non-complete combustion of fuel, and has the symbol q_3 ,%
- Heat loss with mechanical no combustion (for coal fuel), symbolized by his symbol q_4 %
- Heat loss in the atmosphere around boiler, and that has the symbol q_5 ,%
- Heat loss with slag (for coal fuel), and has the symbol q_6 ,%

So equation to find ηg of boilers which burn heavy fuel oil by indirect method is :

$$\eta_g = 100 - q_2 - q_3 - q_5 \tag{3}$$

It is known that the equations of finding heat losses are long and complex, and therefore, the equation of finding (η_g) by indirect method takes long time when account, especially since this method is used during the tests. So it is here came the need to obtain equation equivalent easier not abandon accurate to help boiler test engineer or technician to determine (q_2), and thus (η_g) in the case while doing tests to assess the status of the boiler in front of him to develop modifications immediately to improve the economic work that he wanted to.

III. . Research Methodology

For find simplified, and not lacking equivalent accuracy equation to calculate the thermal losses with gas emerging (q_2) of the boiler that burns heavy fuel oil, research methodology has adopted the following points:

1. Constant coefficients negligence or indicators of unidentified numerical value is very small, or considered equal to the right one if it was worth close to him.
2. Give unknowns indicators, which can not be neglected the infectious average values taken from the literature, or known values taken from the specifications or credit accounts for certain boilers. We have taken the russian boiler (E-160-100ГМ) operating in Al_Hiswa thermal power plant in the city of Aden as a reference for these values.
3. Whereas losses thermal boilers that burn heavy fuel oil along q_2 is q_3 and q_5 , and to keep the research methodology is simplistic without prejudice to accurately results have been negligent heat loss with chemical no combustion q3who expresses uncompleted combustion in the furnace (at the inadequate of air or bad mixing with fuel, etc.), and so on the grounds that the combustion is mostly well. The heat loss in the atmosphere around boiler q_5 can be found to the relationship [1]:

$$q_5 = q_{n5} \left(D_n / D_a \right) \tag{4}$$

where q_{n5} -is the ratio of heat loss in the atmosphere around boiler at nominal boiler load, and this percentage varies depending on the nominal load of the boiler, and taken from references (which is equal to 0.65 of the boiler E-160-100 at nominal load 160 t/h).

IV. Results and Discussion

Following the foregoing methodology we were able to reach the required equation as follows:

As the steam boiler (or any other boiler such as water heating boilers, etc.) that uses heavy fuel oil can be considered an organ to convert the chemical energy of fuel into thermal energy utilized most part of it to turn water into steam (or heated in a boiler heating water), with the loss of the other part of this energy.

To accomplish this function is provided with a quantity of energy powered which we will call "full inlet energy" (Q_F), which is a total energy given to boiler , as energy carried with the same fuel, with fuel spraying steam, with air heating and heating fuel oil, etc., plus cold air energy (Q_{air}) taken from the air needed for combustion, to give us as a result of the interaction process components of the fuel with air in complete combustion (q_3 =0) thermal energy utilized for the most part (Q_{use}) to turn water into superheated steam (or to heat the water to the desired degree in water heating boiler), and lost the other part(Q_{loss}) with gas combustion products through the chimney (Q_g) and across the boiler through the walls to the ambient (Q_a), "Fig. 1," and they are the main source of heat losses, which characterize any boiler practical in all circumstances.

Note - the amount of heat loses with exhaust gases Q_g equal the amount of heat energy emerging with exhaust gases (Q_G) minus (Q_{air}).

So it can formulate an equation for the thermal balance of the boiler as follows:

$$Q_F = Q_{use} + Q_{loss} \tag{5}$$

$$Q_F = Q_{use} + Q_g + Q_a \tag{6}$$

$$Q_F - Q_{use} = Q_G - Q_{air} + Q_a \tag{7}$$

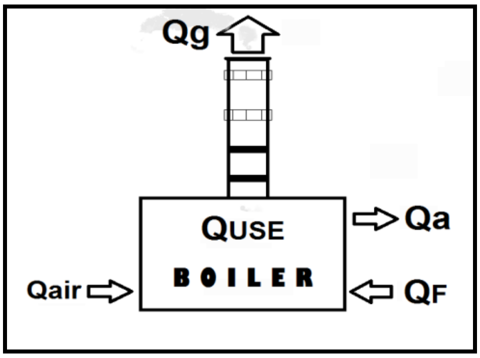

Figure 1. The boiler heat balance

To convert the limits of this equation to percentages multiply each end by $100/Q_F$:

$$(100Q_F/Q_F) - (100Q_{use}/Q_F) = [100(Q_G - Q_{air})/Q_F] + (100Q_a/Q_F) \tag{8}$$

looking to the equation (8), we find that the limit $(100Quse/Q_F)$ is the coefficient of the overall boiler efficiency (η_g) (From the definition of efficiency coefficient , equation no 1), and we find that the limit ($100Qa/Q_F$) is the percentage of heat loss in the atmosphere (q_5) .

So equation (8) can be written as follows:

$$100 - \eta_g = \frac{100\ \ Q_G - Q_{air}}{Q_F} + q_5 \tag{9}$$

$$\eta_g = 100 - \frac{\left[100\left(Q_G - Q_{air}\right)\right]}{Q_F} - q_5 \tag{10}$$

Here we can see that:

$$q_2 = \frac{100(Q_G - Q_{air})}{Q_F} \tag{11}$$

The heat energy that came out of the boiler with combustion products (Q_G) can be found by the following formula [1].

$$Q_G = c_g x\ t_{fg} x\ V_g \tag{12}$$

Similarly can find the amount of thermal energy with cold air (Q_{air}) through the relationship [2] :

$$Q_{air} = \alpha_{fg} x\ c_a x\ t_{ca} x\ V_a \tag{13}$$

So we can write the equation (11) as follows:

$$q_2 = \frac{100\left(c_g x\ t_{fg} x\ V_g - \alpha_{fg} x\ c_a x\ t_{ca} x\ V_a\right)}{Q_F} \tag{14}$$

But Vg can almost be equal [1]:

$$Vg = \alpha_{fg} x\ V_a x\ k \tag{15}$$

where coefficient (k) is a numeric value approximating the right to one, therefore, can be considered equal to 1.

It can be also approximately $c = c_g = c_a$ [1], so equation (14) can be written as follows:

$$q_2 = \frac{100\left(c_g x\ t_{fg} x\ V_g - \alpha_{fg} x\ c_a x\ t_{ca} x\ V_a\right)}{Q_F} \tag{16}$$

$$q_2 = \frac{100\ x\ \ c\ \ x\ \ V_a x\, \alpha_{fg}\left(t_{fg} - t_{ca}\right)}{Q_F} \tag{17}$$

By continuing to follow the methodology followed by this research we give an average value for (c) of tables as specialized average numerical values of (c_g) and (c_a), where the value of (c_g) at a temperature of gases emerging 150 C^O (temperature average for gas) is 1.71 [3], and the value of (c_a) equals 1.32 when the temperature of the cold air medium 30 C^O [4] .

So c = 1.516, and given the values of (V_a) and (Q_F) of the reference values of the Russian boilers which working in Al-Hiswa power plant [3] V_a = 10.8 and Q_F = 42570.

Putting these values in equation (17) we get the final version of the simplified equation to find the proportion of boiler heat loss with exhaust gases (q_2):

$$q_2 = \frac{\alpha_{fg}\left(t_{fg} - t_{ca}\right)}{26} \tag{18}$$

And placing them in the equation (10) we get version of simplified equation to find overall boiler efficiency factor:

$$\eta_g = 100 - \left[\frac{\alpha_{fg}\left(t_{fg} - t_{ca}\right)}{26}\right] - q_5 \tag{19}$$

V. Discussion

1. From the final version of the equation developed to find the value of (q_2), and also used to find ηg can read

a lot of useful inferences about heat loss (q_2) in particular, and on the efficiency of the boiler in general, such as:

A. Clearly it can be observed that the most important indicators affecting the efficiency of any boiler in general and specially in heat loss with exhaust gases is the temperature of the gases emerging from the boiler (t_{fg}) , cold air temperature supplied to the boiler (t_{ca}) and coefficient of excess air (α_{fg}).

B. (q_2) can be equal to zero only when exiting gases from the boiler at a temperature equal to the temperature of the cold air, and this is practically difficult to achieve.

C. We can say that the number 26 has significance physical task .If reflect on the same formula and on the unit of measurement that owned this number ($_C{}^0$ / %) , we find that the number 26 is the amount of temperature to lose with every 1% of the value of (q_2) when $\alpha_{fg} = 1$.

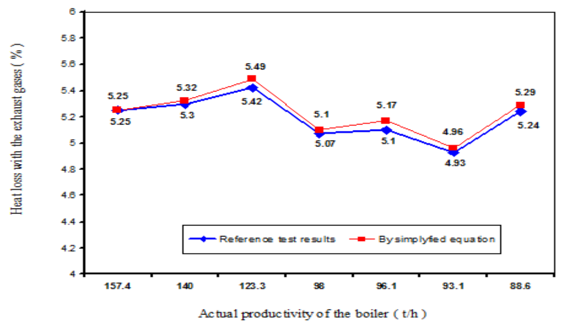

Figure 2. Comparison with the results of reference tests of boiler no. 1 - Al_Hiswa thermal station - Aden 1986

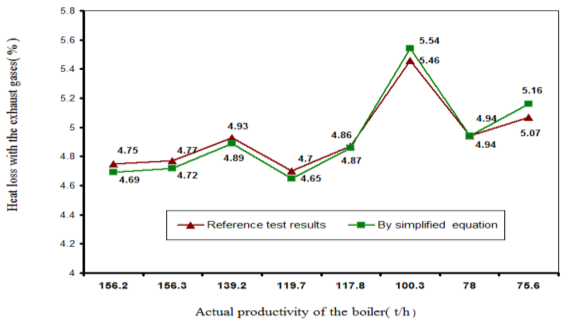

Figure 3. Comparison with the results of reference tests of boiler no. 2 - Al_Hiswa thermal station – 1987

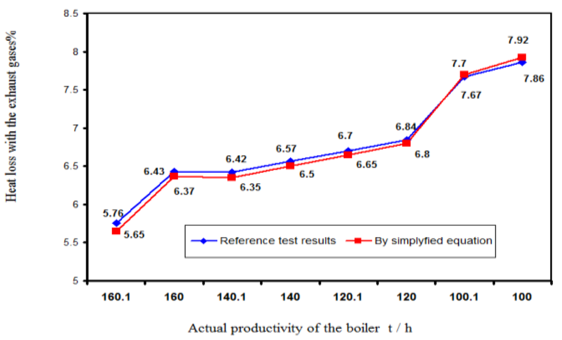

Figure 4. Comparison with the results of after overall maintenance test of boiler no. 3- Al_Hiswa thermal station 2005

2. To find out how accurate our derived equation to find (q_2) , as well as the accuracy of finding (η_g) through it, we compared our results the results of reference tests of the boiler (E-160-100 ГМ) operating in the station Al-Hiswa thermal plant in the city of Aden, which was conducted after the initial operation in the eighties of the last century[5], [6], and also the results of the tests carried out in the year 2005 after the overall maintenance, which was calculated through a special computer software by Russian maintenance company [7], the results were excellent, the delinquency rate of (q_2) was very small , it did not exceed 1.91 %, but sometimes it was zero (See figures no 2, 3 and 4). In other side we got completely identical outcomes, the percentage deviation in finding (η_g) did not exceed 0.1%, and sometimes results also matched.

VI. Conclusions

1. Mathematics not prevent human of innovation easiest ways to help him to achieve the same results at worst very touching that may be obtained by others to follow more complex mathematical solutions.

2. Engineers can check and adjust the boilers using the simplified equation derived in this paper to find heat loss with boiler flue gases that burns heavy fuel oil and thus In record time (within one minute) and with high accuracy, and will not delay it however, the time in which it will analyze the sample of exhaust gases to find the percentage of oxygen to be through to find the value of coefficient of excess air (α_{fg})

3. (η_g) can be found in the boilers that burn coal fuel using the derived equation to find (q_2) and after the inclusion of other losses coal boiler.

4. Equation formula No. (19) to find (η_g) is a simplified version of the known formula "indirect method " for boilers that burn heavy fuel oil, but the remarkable thing is the equation derived to find (q_2).

5. As a result of its simplicity and lack of boundaries where it can use the equation derived to find (q_2) in computer applications (soft wear) to handheld digital gas analysers, which currently used extensively in the test of the boilers around the world.

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Salah Salem Ali Humadi
Place/Date of Birth: Aden-Yemen/1960 Master of since –Thermal Power Plant – Belarusian Technical University – Minsk -Belarus Republic, 1988. His current post- Head of Efficiency and Test Department – Al Hisswa Power Plant – Aden.