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Research Paper

Thermal Balance and Efficiency Calculation in High Pressure Boiler Control Volume according to ASME-PTC4 Standard

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1. ABSTRACT

Based on the design of boilers in the most optimal operating mode, the percentage of energy losses, has a strong impact on the efficiency of these equipment. By identifying the sources of energy losses and finding solutions to reduce fuel consumption and save energy, an important step can be taken to improve the efficiency of boilers. In this research, the thermal performance and operational efficiency of the boilers of the Isfahan refinery are studied. The ASME PTC4 is the reference code for boiler performance testing, which accurately determines the performance of boilers based on their technical and operating specifications.The sources of heat losses in the boiler assembly are identified and significant losses are specifically investigated to propose the solution**.** To reduce the remarkable losses and increase the boiler efficiency, installing an economizer to use the heat available in the boiler stack to heat the boiler inlet water, is recommended.

Keywords: Steam Boiler, Heat Loss, Thermal Efficiency, Performance Test.

2. INTRODUCTION

The most important task in the analysis of boiler heat recovery is to analyze the unit under study from an energy perspective and to identify the recoverable wasted energies in the system. The heat balance of the boiler must be carried out in such a way that the desired efficiency, the desired exhaust conditions, the desired steam conditions and the desired power are provided. The purpose of performing a heat balance on the boiler is to obtain the total energy that is required in the boiler. According to the control volume, the system inputs and outputs are determined and the boiler heat balance is performed accordingly.

3. CALCULATING THE THERMAL EFFICIENCY OF A STEAM BOILER

To calculate the thermal efficiency according to the first law of thermodynamics, an appropriate control volume must be selected. According to the ASME PTC 4 standard, the overall calculation of the thermal efficiency of a steam boiler is performed in two ways: input-output (direct method) and heat loss (indirect method). In the direct method, the input and output energies are calculated and the efficiency is calculated from the ratio of useful output to input. In the indirect method, efficiency is calculated by measuring losses. Some of the losses are energy from the flue gas coming out of the stack, radiation loss, and convection [1].

4. IMPORTANT FACTORS FOR THE THERMAL EFFICIENCY OF A STEAM BOILER

According to the losses calculated based on the boiler efficiency test reference standard, the main factors affecting efficiency include flue gas temperature, excess air quantity, ambient temperature and air humidity [2]. As the flue gas temperature increases, the mentioned losses become larger, therefore, reducing the flue gas temperature is considered one of the most important factors affecting thermal efficiency. As the amount of excess air increases, the volume of flue gas increases, which increases losses and subsequently reduces efficiency, so choosing the appropriate percentage of excess air is of great importance. As the temperature

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decreases according to the relationships described, the temperature difference between flue gas and air increases, which itself is a factor in increasing losses. The next item is air humidity, even if its amount is small, but in areas where humidity is high, the effect of this type of loss will be significant.

5. ENERGY BALANCE AND FUEL ANALYSIS

This section discusses how to calculate the amount of fuel consumed in a steam boiler. The amount of energy consumed in a steam boiler is equal to the amount of energy that the superheated steam leaves the superheater plus the amount of heat that is transferred to the outside as boiler discharge water [3].

$$\dot{Q}_{tot} = \dot{m}_s (h_{fw} - h_s) + \dot{m}_{bd} (h_{fw} - h_{bd}) \quad (1)$$

In the above equation, $\dot{m}_s$ and $\dot{m}_{bd}$ are the flow rates of superheated steam and discharge water and h_{fw} , h_{bd} and h_s are the enthalpy of feed water, discharge water, and superheated steam, respectively. While the thermal efficiency, and the total net energy calculated were obtained previously, the fuel gas consumption is obtained according to equation 2.

$$\dot{Q}_{tot} = B \times H_u \times \eta_{th} \quad (2)$$

In the above equation, B is the fuel flow rate and H_u is the lower heating value of the fuel.

6. CALCULATING HEAT LOSSES AND RESULT

Based on the thermodynamic characteristics of the boiler inlet and outlet, and by investigating the temperature of the flue gas exiting from the stack and the percentage of excess air, the results of the analysis of wet and dry flue gas in the boiler are obtained. Then, using the obtained results and the heating value of the fuel, the results of the calculations in Table 1, including boiler losses and the boiler efficiency, are calculated [4].

Table 1. Thermal efficiency, fuel consumption and flue gas production in the boiler

Item	Boiler Duty Without Eco	Unit	Fuel Gas Firing-70%
H_u	Lower Heating Value	kcal/kg	10,892.6
L_d	Dry Gas Loss	%	14.14
L_f	Fuel Moisture Loss	%	2.58
L_a	Air Moisture Loss	%	0.40
L_c	Unburned Loss	%	0.00
L_r	Radiation Loss -ASME	%	0.44
L_u	Uncounted Loss	%	1.00
L_{tot}	Total Loss	%	18.563
η_{th}	Boiler Efficiency	%	81.44
$\dot{Q}_{tot}$	Boiler Duty Net	kcal/hr	105,413,907
		MW	122.5
B	Fuel Consumption	kg/hr	11,884
$\dot{m}_a$	Air Flow	kg/hr	257,842
$\dot{m}_g$	Flue Gas Flow	kg/hr	269,726
$\dot{V}_g$	Flue Gas Flow	Nm^3/hr	217,171

To compare the characteristics of boiler losses, the calculated losses at MCR, the Maximum Continuous Run of the boiler, 70% of its nominal capacity, are shown in Figure 1. As can be seen, the characteristics of the loss due to dry air are very significant compared to other losses [4]. Comparing with the nominal capacity of the boiler, this amount of heat loss causes energy loss and increases environmental pollutants as well.

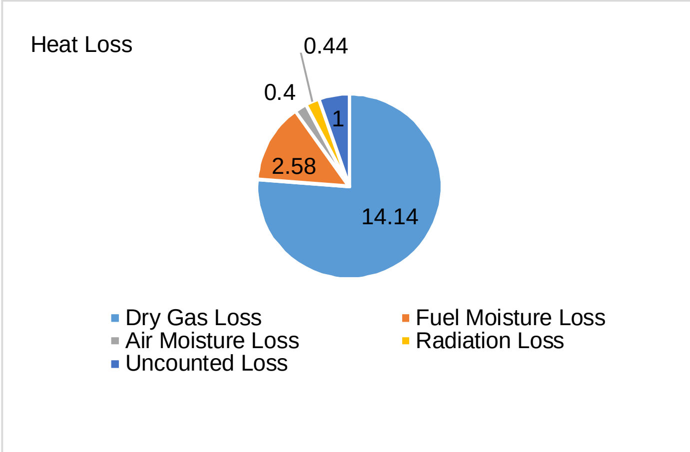

Figure 1. Comparison of heat losses obtained from the boiler heat balance

7. CONCLUSION

According to the results of heat losses, losses due to dry air have the largest share among other losses. Refering to the data in Table 9, it can be seen that no more than 18% of the energy from combustion does not enter the heat transfer process to the boiler fluid and most of these losses mainly losses due to dry gas, are discharged through the stack. In order to recover the wasted energy, it is proposed to install an economizer to use the heat in the hot gases exiting the stack to heat the water entering the boilers. This will increase the efficiency of the boilers and, while reducing fuel consumption, will prevent the emission of environmental pollutants. From an operational point of view, increasing the temperature of boiler feed water thermal shocks and the boiler operability.

8. REFERENCES

[1] Rehan, A., Habib, M. A., Elshafei, M., & Alzaharnah, I. T., Modeling time variations of boiler efficiency. Journal of Energy Resources Technology, 5, pp. 140, 2018.

[2] Purseth, S., Dansena, J., & Desai, M. S. Performance Analysis and Efficiency Improvement of Boiler-A Review. Int. J. Eng. Appl. Sci. Technol, 12, pp. 326-331, 2021

[3] Men, Y., Liu, X., & Zhang, T. A review of boiler waste heat recovery technologies in the medium-low temperature range. Energy, 237, pp. 121560, 2021.

[4] Behzadi A., Abbasian arani, A., A Numerical optimization of water tube boiler energy recovery using a new economizer. International Journal of Thermofluids, 26, pp. 101061, 2025.

[5] Rahimi, F., Atabi, F., Nouri, J., & Omrani, G. Social cost of CO_2 emissions in Tehran waste management scenarios and using life cycle assessment to select the 141 scenario with the least impact on global warming. Advances in Environmental Technology, 1, pp. 11-17, 2021.