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Energy Procedia 100 (2016) 193 – 197

Energy Procedia

3rd International Conference on Power and Energy Systems Engineering, CPESE 2016, 8-12 September 2016, Kitakyushu, Japan

Improvement of Boiler's Efficiency Using Heat Recovery and Automatic Combustion Control System

Ratchaphon Suntivarakorn[a*] and Wasakorn Treedet[b]

[a] Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand.
[b] Farm Engineering and Automation Technology Research Group, Khon Kaen University, Khon Kaen, 40002, Thailand.

Abstract

This research was conducted to improve the efficiency of a fire tube boiler with a fixed gate and screw conveyor for feeding fuel. The efficiency improvement was based on the use of flue gas heat for fuel drying, air preheating before combustion, and controlling amount of air for fuel combustion before entering the combustion chamber using the fuzzy logic control algorithm. The experimental result indicates that using heat recovery and fuel drying reduces 3%wt of fuel moisture content and boiler efficiency increases 0.41%. Preheating air means a 35°C increase of temperature or a 0.72% increase of boiler efficiency. The average accuracy of air control is 89.15%, indicating a 4.34% increase of boiler efficiency. If the three systems are operated simultaneously, 5.15% increase of boiler efficiency will be achieved or 246.88 tons/year saving of fuel.

Peer-review under responsibility of the organizing committee of CPESE 2016

Keywords: Boiler efficiency, Air pre-heater, Fuel dryer, Automatic control

1. Introduction

Boilers are widely used in several kinds of industries. Produced Steam is utilized in different processes or in generating electricity. In 2012 alone, over 10,000 boilers were operating in Thailand, divided into 80% fire tube boilers, 15% water tube boilers and 5% electrical boilers [1]. However, since boilers consume a great amount of power to run, their power efficiency should be improved.

Nowadays, attempts have been made to increase boiler efficiency by recycling flue gas heat, and many techniques and methods have been invented. One is increasing the economizer capacity by altering tube layout, increasing heat exchange tubes [2], controlling flue gas flow passing the economizer [3], reducing the condensing temperature by replacing with low-sulfur fuel [4-5], using flue gas heat to dry biomass fuel before entering the boiler [6], or by automatic combustion controlling of boilers in order to increase combustion efficiency and hence decreasing toxic gases that are released into the environment [7-14], etc. Nevertheless, increasing boiler efficiency principally requires consideration of power loss of boilers. Generally speaking, the ratio of heat loss of a boiler that

* Correspondingauthor. Tel.: +66-4320-2845; fax: +66-4320-2849.
E-mail address: ratchaphon@kku.ac.th.

Peer-review under responsibility of the organizing committee of CPESE 2016
doi:10.1016/j.egypro.2016.10.164

uses rigid fuel happens mainly from loss of heat with flue gas, followed by heat loss from evaporation of Hydrogen in the fuel [15].

Hence in this research we conducted a case study to improve boiler efficiency of a fire tube boiler using rigid fuel for combustion. Three methods were attempted, namely controlling the amount of combustion air to reduce heat loss with exhaust gases, using recovery heat from flue gas to dry fuel before entering combustion chamber, and using recovery heat to preheat the air before entering combustion chamber. The increasing boiler efficiency of each method was investigated together with the energy required for efficiency increase and safety after improving boiler efficiency.

2. Boiler Description

The 9 tons/hr fire tube boiler in our case study belonged to a factory in Khon Kaen Province, Thailand. It is a fixed gate combustion type using a screw conveyor to feed fuel into the machine in order to produce an average of 2.8 tons of steam per hour for the factory's process at the pressure of 6 bars. Sub-bituminous coal is used as the fuel and the flow rate of combustion exhaust is 4.14 m^3/s at 177°C. The detail of steam production is shown in Figure 1(a) below:

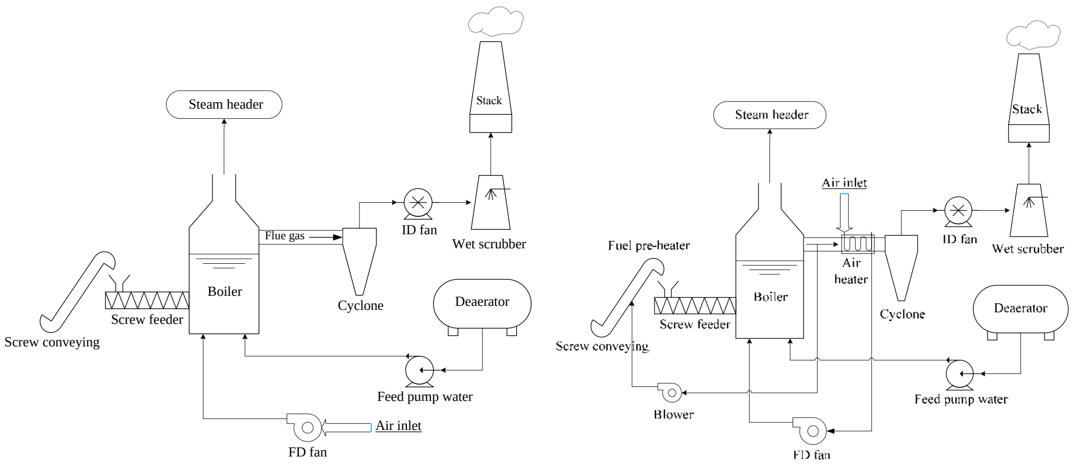

Fig. 1. (a) Steam production system before improvement; (b) Steam generation after installing the heat recovery system

3. Experimental Design and Set-up

3.1. Heat recovery from flue gas for fuel drying and air heater system

The use of flue gas to increase boiler efficiency was divided into two parts, namely, applying the recovery heat to dry the fuel and applying it to preheat the air before entering combustion chamber, as shown in Figure 1(b). Our fuel drying system was working with fuel with moisture content around 30 - 40 wt% in a direct screw conveyor tube. Conveying coal from the stack to the combustion chamber was in 2 stages, first by a screw conveyor, which lifted the coal on a floor and passed it to the screw feeder. The latter fed coal into the combustion chamber as shown in Figure 1(b). Fuel drying system connected exhaust pipe behind the boiler with the screw conveyor in the first stage where the temperature of flue gas was between 120°C - 150°C. This was blown directly on to the coal in the screw conveyor. However, in our study no more than 1.11 m^3/s of flue gas was used.

The heating system used the rejected heat from the boiler as the heat power source. The flow rate of flue gas used in the heating system was 3.03 m^3/s. The layout for heat exchanger is shown in Figure 1(b). The design of the heat exchanger was based on the single-pass cross-flow with both fluids unmixed. Cool air was used as the flowing fluid in the tube and hot flue gas was a fluid outside the tube.

The design result of heat exchanger is shown in Table 1.

Table 1. The design result of heat exchanger

Description	Value	Unit
Overall heat transfer coefficient (U_o)	17.45	$W/m^2\,^oC$
Volumetric flue gas flow rate	3.03	m^3/s
Volumetric air flow rate	2.65	m^3/s
Temperature different logarithm (ΔT_{LMTD})	31.28	-
Heat exchanger surface area (A)	166.15	m^2
Heat recovery from heat exchanger $(Q_{heat\_changer})$	89.82	kW

3.2. Automatic combustion control system: a case study

Automatic combustion control was achieved by measuring the amount of Oxygen gas (O_2) from the flue gas stack in order to find if the amount of air was adequate for combustion. In general, the measured ratio of O_2 after combustion of rigid fuel is between 3% - 7% [14]. Any percentage higher than this means too much air for combustion and the FD fan speed should be lowered so that combustion air is less. To automatically control O_2, we need to know the correlation between the amount of air needed for real combustion in the boiler and the amount of O_2 remained from combustion. This correlation is used as the control basis. The correlation value between real amount of combustion air in the boiler and the amount of O_2 can be found from the experiment. We adjusted the frequency values of the FD fan inverter control and recorded the oxygen percentages measured at the flue gas stack. The results of the inverter frequency adjustment are shown in Figure 2 and the correlation between the inverter frequency of FD fan and the amount of O_2 measured in the flue gas from Equation (1):

$$(\%O_2) = -0.1548f + 16.702 \tag{1}$$

Equation (1) was derived from the real experiment. It is a linear equation and hence application of the system control theory using the Fuzzy Logic Control Algorithm relied on two control variables, i.e., proportion of O_2 $(\%O_2)$, the independent variable obtained from sensor which is used to find the appropriate frequency to order the inverter and the inverter frequency (f); and the dependent variable obtained from mathematic calculation in order to order the inverter. The mathematic equation for fuzzy logic control algorithm to control inverter frequency in order to obtain the required amount of O_2, is shown in Equation (2).

$$(H_Z) = \frac{\left[2(\%O_2)_{setpoint} - (\%O_2)_{measure}\right] - 16.702}{-0.1548} \tag{2}$$

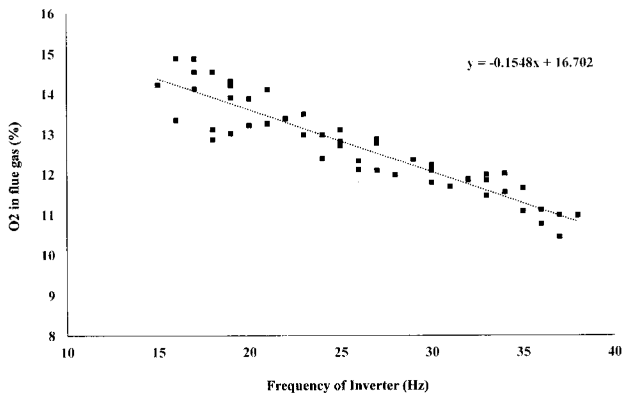

Fig. 2. Correlation between the inverter frequency of FD fan and the amount of O_2 measured in the flue gas.

4. Result and Discussion

4.1. Heat recovery from flue gas

From experimenting on the fuel drying system using a 5hp blower to recover flue gas heat to blow the fuel in the screw conveyor, we found that the time required for drying coal was from 40 to 80 minutes. The amount of flue gas was between 0.19 and 0.55 Nm^3/s, which reduced an average of 3 %wt of moisture from the coal and increased roughly 16 - 18°C from formal temperature. An average of 1.73 kWh per hour was consumed by the blower. How much moisture can be removed by fuel drying with recovery heat depends on the amount of flue gas used in the drying, the rate of fuel feed into the screw conveyor which in turn depends on the steam loading capacity of the boiler at that particular time, and the initial moisture content of the fuel before the drying process begins. If coal moisture content is high, it may not be effectively removed when compared to coal with low moistrue content.

Experiment on increasing efficiency of boilers by preheating air before combustion by means of a 90kW heat exchanger was conducted through sampling 20 samples to analyze temperature rates. It was found that air temperature could be increased from 30 - 35°C to 65 - 70°C. The flue gas temperature reduced from about 160 - 175°C to 140 - 155°C. This is different from the predicted discharge temperature from the heat exchanger of flue gas and air, which is close to the real experimental result.

4.2. Automatic combustion control system

The experiment on automatic combustion control was based on the Fuzzy Logic Control Algorithm which controlled the FD span input speed only. The ID fan rev speed was kept unchanged. Then O_2 in the flue gas was measured to compare the capacity in air control before and after the experiment. O_2 in the flue gas was regulated at 10% continuously for 24 hr for 2 days. Before combustion air control, O_2 in the flue gas was at 12.24% on average. After using the automatic combustion control system the average O_2 in the flue gas decreased to 10.86% on the first day and to 11.33 % on the second day, or control errors at 8.6% and 13.3%, respectively. We also found from the experiment that the heat value and fuel moisture content had high impact on combustion control. If combustion heat exceeds 20 MJ/kg and moisture content lower than 32 %wt, efficiency of the system's control capacity would be very high, yielding a control error of less than 5%.

4.3. Boiler Efficiency

Comparison of boiler efficiency that increased was conducted to see the increased efficiency, energy consumption, ratio of steam per fuel, and fuel saving of each system, as shown in Table 2.

Table 2 Boiler efficiency increase from system improvement.

Description	Before	Fuel drying	Air heater	Combustion control	Total
Boiler Efficiency (%)	76.48	76.89	77.20	80.82	81.63
Energy consumption (kWh)	-	1.73	-	-	1.73
Ratio of steam per fuel	5.87	5.90	6.12	6.21	6.41
Fuel saving (Tons/year)	-	18.50	32.50	195.88	246.88

Table 2 demonstrates that before improvement, the boiler efficiency was 76.48%. After installing the fuel drying, air preheating, and automatic combustion air control systems, the boiler efficiency could be increased to 76.89%, 77.20%, and 80.82%, respectively for each system. The amounts of annual saving are 18.50, 32.50, and 195.88 tons, respectively. When operating altogether, the boiler efficiency increased to 81.63% or an amount of 246.88 tons of fuel saving per year. The fuel drying system is the only technology consuming power for the electric blower at 1.73 kWh or a cost of fuel loss instead of blower's electric consumption of 0.346 kg/hr (when considering fuel heat of 18,000 kJ/kg).

5. Conclusion

Improvement of boiler efficiency in this research was performed by using the recovery heat for fuel drying and by installing a 5hp blower to recover flue gas from a stack to blow directly on the fuel screw conveyor. The heat recovery for preheating air before entering combustion chamber used a 90 kW heat exchanger and a combustion air control system was installed based on the theory of fuzzy logic control algorithm to control FD fan revolutions.

Experiment on heat recovery for fuel drying shows that an average of 3% moisture content was removed, increasing the temperature of fuel at 16 - 18°C higher. However, as we had a blower to recover flue gas heat, the average cost of electricity was 1.73 kWh or the cost of fuel loss instead of electric energy use in a blower of 0.346

kg/hr. In preheating air with flue gas heat before entering combustion chamber, we found the temperature could be raised at 35°C. The average temperature of flue gas leaving the heat exchanger was in the range of 140 - 155°C, which did not result in any condensation from SO_2 that can cause damage to the machine. In automatic combustion control by setting the O_2 in flue gas at 10%, it was found that the two experiments in 48 hours were able to control flue gas O_2 at 10.86% and 11.33% or control errors of 8.6% and13.3%, respectively.

After improvement of the boiler with our approach, the fuel drying system, preheating system, and automatic combustion control system were able to increase the boiler efficiency at 0.41, 0.72, and 4.34%, respectively. If the three systems are operated together the boiler efficiency will be increased at 5.15%, an equivalent of fuel saving of 246.88 tons per year.

Acknowledgement

The authors acknowledge the grant from Khon Kaen Fishing Net Factory Co., Ltd and Innovation Coupon project on the Federation of Thai Industrials (F.T.I.) for financial support. The authors are also grateful to the Farm Engineering and Automation Technology Research Group, Khon Kaen University for technical support of this research.

References

[1] CS Inspect co,. LTD. Boiler; 2013 [Available from http://www.cs-inspected.com/boiler.html] .

[2] Kumar PR, Raju VR, Kumar NR, Krishna Ch V. Investigation of Improvement in Boiler Efficiency through Incorporation of Additional Bank of Tubes in the Economiser for Supercritical Steam Power Cycles. International Journal of Engineering Research and Development 2012; **4**: 94-100.

[3] Gibbs BM. Boiler Fuel Savings by Heat Recovery and Reduced Standby Losses. Heat Recovery Systems and CHP 1987; 7: 151-157.

[4] Blanco JM, Pena F. Increase in the Boiler's Performance in Terms of the Acid Dew Point Temperature: Environmental Advantages of Replacing Fuels. Applied Thermal Engineering 2008; **28**: 777-784.

[5] Suntivarakorn R, Sakkampang C. A Study of Boiler Efficiency Using Blended Fuel between Glycerine and Heavy Oil Fuel. KKU Engineering Journal 2010; **37**: 109-119.

[6] Li H, Chen Q, Zhang X, Finney KN, Sharifi VN, Swithenbank J. Evaluation of a Biomass Drying Process Using Waste Heat from Process Industries: A case study. Applied Thermal Engineering 2012; **35**: 71-80.

[7] Ozaki N, Harayama K, Shinohara W, Hayashi S. Recovery Boiler Intelligent Control. Annual Review in Automatic Programming 1991; 16: 139-143.

[8] Wen S, Yongcheng J. The Research and Application on Intelligent Control in Boiler Combustion System. Procedia Engineering 2011; **23**: 167-173.

[9] Jing L, Jingxia N, Jianhua L, Shaofeng L, Zhi L. Intelligent Control System of Stack-boiler. Physics Procedia 2012; **25**: 1205-1211.

[10] Prokhorenkov AM, Sovlukov AS. Fuzzy Models in Control Systems of Boiler Aggregate Technological Processes. Computer Standard & Interfaces 2002; **24**: 151-159.

[11] Saha PK, Shoib M, Kamruzzaman J. Development of a Neural Network Based Integrated Control System of 120 ton/h Capacity Boiler. Computer & Electrical Engineering 1998; **24**: 423-440.

[12] Liu H, Chaney J, Li J, Sun C. Control of NOx Emissions of a Domestic/Small-scale Biomass Pellet Boiler by Air Staging. Fuel 2013; **103**: 792-798.

[13] Liao Z, Dexter AL. The Potential for Energy Saving in Heating Systems Through Improving Boiler Controls. Energy and Buildings 2004; **36**: 261-271.

[14] Yao HM, Vuthaluru HB, Tade MO, Djukanovic D. Artificial Neural Network-based Prediction of Hydrogen Content of Coal in Power Station Boilers. Fuel 2005; **84**: 1535-1542.

[15] Rayaprolu K. *Boilers for Power and Process*. Boca Raton: CRC Press, 2009.