Homepage Journal http://jurnal.polsri.ac.id/index.php/austenit

AUSTENIT VOL. 15 NO.2, OKTOBER 2023 **ISSN : 2085-1286 E-ISSN : 2622-7649**

THE ENHANCEMENT OF TEMPERATURE IN BOILER BY STEAM INJECTION

Iriani Reka Septiana[1)*], Rima Daniar[1)], Dilia Puspa[2)], Nurul Kholidah[2)]

[1)] Energy Engineering, Politeknik Negeri Sriwijaya, Jl. Srijaya Negara Bukit Besar – Palembang 30139

[2)] Industrial Chemical Technology, Politeknik Negeri Sriwijaya, Jl. Srijaya Negara Bukit Besar – Palembang 30139

*Corresponding email: iriani.reka.septiana@polsri.ac.id

ARTICLE INFORMATION

Revised
03/08/2023

Accepted
23/10/2023

Online Publication
31/10/2023

doi:

10.53893/austenit.v15i2.7043

ABSTRACT

The boiler is equipment widely used in various industrial sectors such as power plants, fertilizer plants, paper mills, and others. The combustion chamber is an important part of the boiler which can determine the quality of the steam product. The main problem has happened in combustion chambers such as unburned hydrocarbon/carbon loss which is called fouling. Fouling has occurred in many boilers, which use coal or oil as fuel for the production of steam and decreases boiler performance. The purpose of this research is to increase temperature by adding steam injection to reduce fouling to compare with and without steam injection. Two indicators that have the potential to enhance heat transfer are the elevation in temperature and the reduction in fouling percentage. The variables in this research were air flow of 15 L/min, 17,5 L/min, and 20 L/min and steam injection pressure of 2 bars, 3 bars, and 4 bars. The maximum temperature enhancement was 37,5% in 15 L/min of air flow at a steam injection pressure of 2 bars and 3 bars. The maximum fouling abatement was 78,57% in 15 L/min at a steam injection pressure of 4 bars.

***Keywords** : Boiler, Fouling, Steam Injection*

1 INTRODUCTION

The utilization of energy is categorized into two main aspects: the utilization of renewable energy and the utilization of existing energy through the enhancement of equipment efficiency (energy conservation) (Azharuddin et al, 2013). As a vital utility and primary energy provider, the boiler's efficiency undoubtedly requires improvement.

The boiler serves as a crucial heat transfer apparatus in various industrial sectors, functioning both as a primary device and a utility. The combustion chamber, a key component within the boiler, significantly influences the quality of the produced steam and indicates the boiler's performance. As a result, enhancing boiler performance is critical, with possible improvements estimated to be in the region of 1 - 2% within the combustion area. The fundamental difficulty in the furnace is fouling, which lowers the transfer of heat from fuel combustion, resulting in a decrease in boiler efficiency. Fouling occurs throughout the convection zone sections, with the greatest difference in pressure reported over the producing bank (Eaton et al, 2007).

The fouling properties of a fluid when it interacts with a surface used for heat transfer are determined by several key parameters, including the fluid's flow velocity, temperature at the surface, fluid bulk temperature, heat transfer surface substance composition, heat transfer surface geometry, and specific fouling fluid properties (Awad et al. 2007).

When ash accumulates on furnace walls, especially in the radiating area, it becomes very viscous and creates a liquid coating, this is referred to as "slagging." When the deposit, on the other hand, is made of condensed elements and takes the form of a dry accumulation, as is common in the convective area, it is referred to as "fouling." (Hare et al , 2010)

A similar set of events characterizes fouling processes. In most circumstances, the sequence of events can have an influence on heat exchanger equipment performance (Mostafa,2011:509). The five major phenomena are characterized as fouling. Initiation, particle transport to the heat transfer surface, attachment of fouling particles to the surface involves both physical and chemical processes, removal or re-entrainment of deposits from the surface, and transport from the deposit-fluid interface to the bulk of the fluid once the deposits are sloughed.

The fouling factor, Rf (fouling resistance), which is tested by a test section or estimated from the decreased capacity of an operational heat exchanger equipment, indicates the entire process of fouling.

Technologies aimed at mitigating fouling include soot blowing, internal cameras, and TIFI (Targeted in Furnace Injection Technology), among others (Ibrahim.2012). Steam injection has the additional bene t of enhancing thermal efficiency, leading to reduced fuel consumption for maintaining the same power output. This improvement in performance offers both environmental and efficiency advantages (Kayadelen et al. 2014)

There are several techniques and technologies available to prevent deposition issues in boilers. In addition to steam injection, technologies utilize water jets in the boiler. It is suitable for gaseous fuel. A heat recuperation boiler with water spray (HR-B/WS) is a boiler with a water spraying system. Water is sprayed into the input airstream or the chemical reaction zone within the furnace to aid in the heat recovery process (Lee et al., 2020).

An analogous technology closely related to soot blowing involves steam injection while the boiler is operational, as demonstrated by Djoni Bustan (2007). Steam injection not only reduces fouling but also enhances the heat transfer received by the water within the tubes. A rise in the surface temperature and enthalpy of the steam product indicates enhanced heat transfer. Furthermore, the type of fuel used significantly impacts the quality of the steam product, making it an additional aspect to consider beyond heat transfer.

Extensive research has been made especially on fouling abatement and increasing the boiler performance. The unwanted deposit including slagging, fouling, and coke decreases the boiler's performance. Trying to modify condition operation majority pressure steam injection to increase reduce fouling in boiler and as well as improve boiler performance.

The ultimate aim of this study is to increase temperature by adding steam injection to reduce fouling to compare with and without steam injection. In this work, the steam injection will be studied combined with increasing temperature as well as boiler performance and fouling abatement.

2. MATERIALS AND METHODS

The research process involves running the boiler according to the study's matrix, collecting data, and evaluating the increase in heat transfer.

The materials utilized in this study comprise water, as specified in Table 1, and Industrial Diesel Oil (IDO) as the designated fuel for the combustion chamber. The chosen fuel for this research is IDO, which is a blend of diesel and heavy fuel oil. Primarily employed for heating, power generation, and in small-scale industrial and hospitality applications, IDO fuel will undergo combustion to generate a heat source for steam production. The furnace's heat is obtained from the combustion process, as well as the sensible heat of the preheated combustible air. When oil fuels are burnt, they generate flames of different brightness, depending on the burner design, quantity of atomization, and the proportion of surplus air used (Kern, 1965: 689).

Oil fuels are generally constituted of a blend of highly heavy hydrocarbons with larger quantities of hydrogen than coal fuels. Simultaneously, because oil contains less carbon than coal, it requires less combustion air to complete combustion. As a consequence, burning oil emits less CO_2 than burning coal but more CO_2 than burning natural gas. Furthermore, the majority of the pollutants produced by coal combustion are likewise produced by oil combustion.

Steam generators have been powered by both the product of distillation fuel oils and residual oils. In comparison to gas burning, the boiler architecture stays basically constant for distillate oil firing. When employing oil burning, however, a slightly greater fouling factor is used, ranging from 0.003 to 0.005 ft^2 /Btu, as opposed to 0.001 for gas firing (Ganapathy, 2003). Rotary soot blowers installed at each end of the convection area are regarded appropriate for removing surface areas during distillate oil combustion. Heavy fuel oils, on the other hand, need the employment of removable soot blowers. Rotary blowers are also used in oil-fired applications by economizers. Rigid fin tubes with a fin average density of three or four per inch may be appropriate if distillate fuels are used. When burning heavy oil, however, it is advisable to utilize bare tubes or, at most, 2-3 fins per inch. NOx emissions are expected to be greater due to fuel-bound nitrogen, which can account for over 50% of total NOx emissions. It is observed that in oil fire, flue gas recirculation has a less influence on NOx than in gas firing.

The boiler's performance while fired with distillate oil is outstanding. Based on the Lower Heating Value (LHV), the efficiency is approximately identical to that of gas fire. However, there is a difference in efficiency when the Higher Heating Value (HHV) is included. The exhaust gas data analysis with 15% extra air reveals different features. In particular, the exhaust gases include less water vapor and greater carbon dioxide than flue gases produced by natural gas burning.

Additionally, LPG gas with a 3 kg capacity serves as the fuel for the external steam drum.

Table 1. Feedwater Boiler Specifications

Parameter		Water Tube Boiler			
Max. Working pressure [bar]		10 – 20		20 – 30	
General treatment method		Soft water	De-mineralized water	Soft water	De-mineralized water
pH at 25°C		7	7	7	7
Hardness $CaCO_3$	ppm	2	0	2	0
Oil and Fat	ppm	0	0	0	0
Dissolved oxygen	ppm	0.5	0.5	0.1	0.1
pH at 25°C	ppm	11.0-11.5		11.5-11	
M alkalinity $CaCO_3$	ppm	600	300	300	150
P alkalinity $CaCO_3$	ppm	300–400	200	300	100
Total Dissolved solids	ppm	2000	700	1000	500
Chlorine (ion Cl)	ppm	300	-		-
Phosphoric acid ion PO_3/PO_4	ppm	20 – 40	10 – 30	20 – 40	10 – 30
Silica, SiO_2	ppm	200	50	150	40
Hydrazine N_2H_4	ppm	0.05 – 0.3		0.05 – 0.3	
Sulfurous acid ion, SO_2/SO_3	ppm	10 – 20		10 – 20	
Conductivity	µS/cm	2800	1000	1500	750

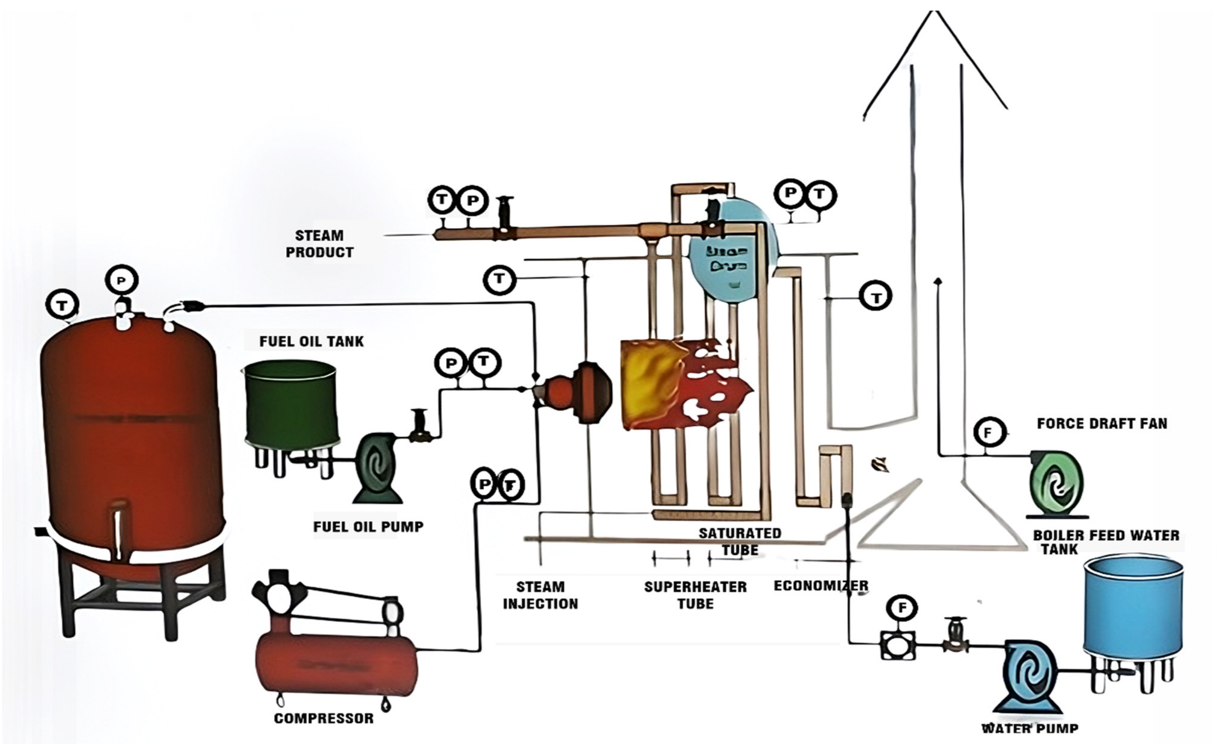

Figure 1. Experimental Process Description in Boiler

The apparatus used in this study can be observed in Figure 1, which depicts a comprehensive schematic diagram of the boiler utilized for this research. Steam injection used in the research in comparison to no steam injection.

Boiler contains two steam drum. steam drum (1) is external equipment to produce steam injection at pressure 2 Bar (120°C), 3 bar (130°C) and 4 Bar (140°C) to the main boiler. Steam drum (2) is internal equipment which is in main boiler. Experimental process is shown Figure 1 for visual understanding.

The reading points for pressure and temperature data can be observed in Figure 1. The measurement instruments employed consist of a temperature gauge and a pressure gauge, both of which are installed on each component of the apparatus. The temperature gauge is used with interval 100-250°C for steam injection and furnace. Pressure gauge is used with interval 0 – 16 bar for steam injection.

Steam injection, referred to as a soot blower, is a technology utilized to mitigate fouling and enhance boiler efficiency. In kraft recovery boilers, the accumulation of fireside deposits on tube surfaces can significantly impair heat-transfer efficiency, leading to elevated flue-gas temperatures and increased plugging of downstream flue-gas passages. To sustain high thermal efficiency and uninterrupted boiler operation, these deposits necessitate removal. During boiler operation, soot blowers employ high-pressure steam jets to effectively blast and remove these deposits.

The strength in terms of mechanical force of the deposit has a considerable impact on the effectiveness of deposit eliminating by soot blowers. The strength of these deposits varies from one boiler to another due to differences in the chemistry of the combusted black liquor and the resulting flue-gas temperature. Furthermore, the strength of deposits also varies from location to location within a boiler, primarily due to differences in deposit chemistry and formation mechanisms.

3. RESULTS AND DISCUSSION

The results obtained from this research consist of three sub-results: an increase in temperature, both in the steam drum and the steam product, an increase in enthalpy in both the steam drum and the steam product, and the distribution and reduction of fouling in the combustion chamber.

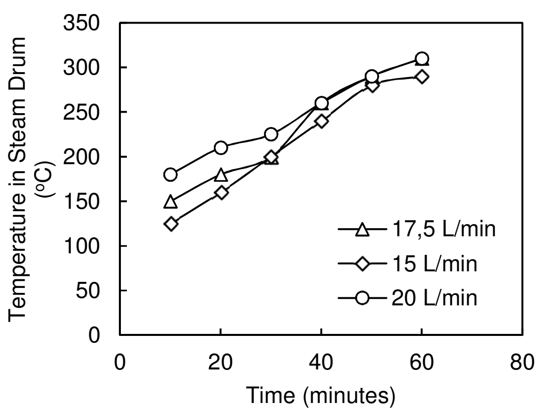

Figure 2. The temperature in Steam Drum for 1 hour (without Steam Injection)

Figure 2 illustrates the temperature in the steam drum for 1 hour with interval 10 minutes which steam was not injected to combustion chamber. The temperature in the steam drum increased from 10 minutes to 60 minutes. In 40 minutes, the temperature of each varied air flow has the small difference temperature. The maximum temperature was 310ºC in 60 minutes with air flow 17,5 L/min and 20 L/min.

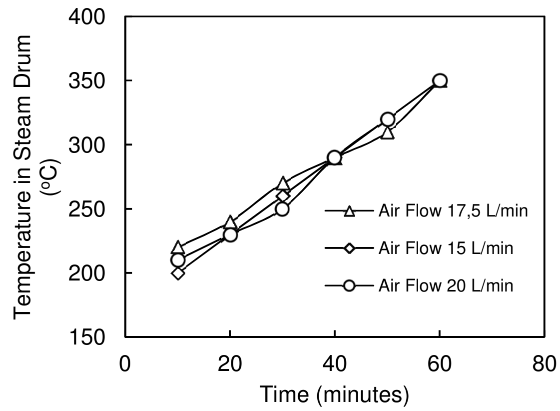

Figure 3. The temperature in Steam Drum for 1 hour (Steam Injection Pressure 3 bar)

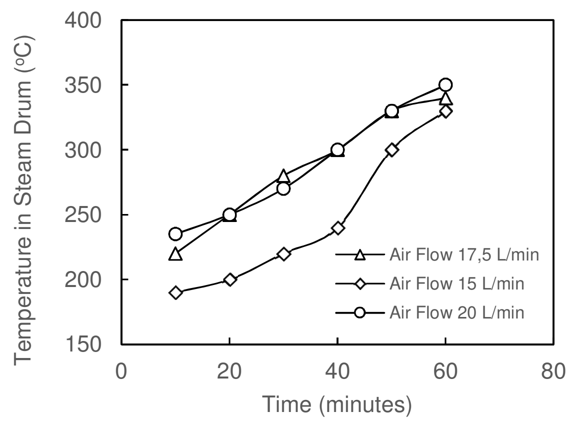

Figure 4. The temperature in Steam Drum for 1 hour (Steam Injection Pressure 4 bar)

Figures 3 and 4 indicate the results of increasing the pressure of the steam injection, which causes a temperature increase according to heat created by the spontaneous interaction among the carbon and steam in the furnace, as well as the chemical reaction between oil and steam. These processes resulted in less fouling throughout the furnace chamber.

Steam injection was observed to increase the temperature inside the steam drum. At an airflow rate of 15 L/minute, the maximum temperature increase recorded was 37.5% within a 10-minute period, with 3 bars of steam injection entering the combustion chamber. Similarly, at an airflow rate of 17.5 L/minute, the maximum temperature enhancement reached 31.8% within 10 minutes, with 3 bars of steam injection entering the combustion chamber. This indicates that a higher airflow rate corresponds to a greater quantity of steam introduced. The amount of injected steam influences the temperature increase, as unburned carbon is readily absorbed by steam, leading to the formation of carbon dioxide through chemical reactions. At a pressure of 4 bars and the same airflow rate, a similar percentage of temperature increase was observed, although the reduction in fouling was more substantial due to both physical and chemical fouling reduction processes, in addition to the effects of steam pressure entering the system.

The addition of steam injection at varying pressures resulted in an increase in temperature and a reduction in fouling within the combustion chamber. Under rich fuel conditions, the oxidation of CO (carbon monoxide) and HC (hydrocarbons) remains incomplete. Steam reforming occurs in the combustion chamber at temperatures around 800℃. This reforming process involves the partial combustion of the fuel in an exothermic reaction with oxygen. The oxygen supplied to the system is sub-stoichiometric, leading to the formation of both CO and CO_2 in the system.

This reaction is exothermic, which enables partial oxidation to occur more readily than steam reforming. As a result of this partial oxidation process, the CO produced is combined with an appropriate amount of steam to facilitate the water gas shift reaction, converting carbon monoxide into carbon dioxide.

Fouling abatement was found to be dependent on steam injection pressure, although other factors could also have an impact. The spreading of soot was controlled not only by uncompleted combustion events, along with by the major feature of the fuel, known as heavy oil. Each heavy oil produced a minimal amount of carbon residue that might contribute to fouling development. As a result, preventing fouling was rated the most important problem for boilers that used heavy petroleum as a fuel.

4. CONCLUSION

The addition of steam injection at varying pressures will increase the temperature and this means increasing the steam enthalpy value in the steam drum because of the heat that comes from the spontaneous reaction between carbon and steam in the combustion chamber as well as from the reaction between fuel and steam. The spread of soot is not only caused by incomplete combustion reactions but also due to the characteristics of the fuel, the majority of which is fuel called heavy oil. Steam injection reduces fouling because the combustion reaction in the furnace reacts almost completely.

The variables in this research were air-flow ratio in 15 L/min, 17,5 L/min and 20 L/min, and steam injection pressure in 2 bar, 3 bar and 4 bar. The maximum of temperature enhancement was 37,5% in 15 L/min of air flow at steam injection pressure 3 bar. The maximum of fouling abatement was 78,57% in 15 L/min at steam injection pressure 4 bar.

REFERENCES

Awad, M. M., El-Wahab, I. A., & Gad, H. (2007). Effect of surface temperature on the fouling of heat transfer surfaces. *surfaces*, page. *21*, 23-39. https://www.researchgate.net/publication/237336142_EFFECT_OF_SURFACE_TEMPERATURE_ON_THE_FOULING_OF_HEAT_TRANSFER_SURFACES

Azharuddin, dkk. Rancang Bangun Alat Boiler Kondensor.2013. Austenit.Vol. 5. No..3 https://doi.org/10.5281/zenodo.4546495

Bustan, M. D. (2007). Effects of Steam Injection Flow in Burner and Outside Water Tube to the Increasing of Boiler Temperature. *ASEAN Journal of Chemical Engineering*, *7*(2), 120-126. Retrieved from https://journal.ugm.ac.id/v3/AJChE/article/view/7685

Eaton, M. A. (2007, January). Analysis of boiler fouling and boiler cleaning methods at the commerce refuse-to-energy facility. In *North American Waste-to-Energy Conference* (Vol. 47896, pp. 119-126). https://doi.org/10.1115/NAWTEC15-3210

Ganaphathy, V. 2003."Industrial Boiler and Heat Recovery Steam Generators: Design, Application, and calculations". Marcell Dekker Inc. New York. https://books.google.co.id/books/about/Industrial_Boilers_and_Heat_Recovery_Ste.html?id=K8Ucuj-Mx-oC&redir_esc=y

Hare, N. M. G. R., Rasul, M. G., & Moazzem, S. (2010, February). A review on boiler deposition/foulage prevention and removal techniques for power plant. In *Recent Advances in Energy and Environment. Proceedings of the 5th IASME/WSEAS International Conference on Energy & Enviroment (EE'10)* (Vol. 23, p. 25). https://www.researchgate.net/publication/229034998_A_review_on_boiler_depositionfoulage_prevention_and_removal_techniques_for_power_plant

Ibrahim, Hassan Al Haj. 2012. "Chapter 3 : Fouling in Heat Exchanger". INTECH https://www.researchgate.net/publication/235338024_Fouling_in_Heat_Exchangers

Kayadelen, H. K., & Ust, Y. (2014). Performance and environment as objectives in multi-criterion optimization of steam injected gas turbine cycles. *Applied Thermal Engineering*, *71*(1), 184-196. https://doi.org/10.1016/j.applthermaleng.2014.06.052

Kayadelen, H. K., & Ust, Y. (2013). Prediction of equilibrium products and thermodynamic properties in H2O injected combustion for CαHβOγNδ type fuels. *Fuel*, *113*,389-401. https://doi.org/10.1016/j.fuel.2013.05.095

Kern, Donald. Q. 1965. "Process Heat Transfer", New York : Mc Graw-Hill Book Company. https://www.scirp.org/(S(lz5mqp453edsnp55rrgjct55.))/reference/referencespapers.aspx?referenceid=2105586

Lee, C. E., & Kim, D. H. (2020). Heat recovery boilers with water spray. Part I: Thermodynamic analysis validation and boiler practicality. *Thermal Science and Engineering Progress*, *18*, 100491. https://doi.org/10.1016/j.tsep.2020.100491