International Journal on Advanced Science Engineering Information Technology

Vol.6 (2016) No. 1
ISSN: 2088-5334

Boiler Retrofit for the Utilization of Biodiesel

Leily Nurul Komariah[#] and Marwani[#]

[#] *Chemical Engineering Department, Sriwijaya University, Inderalaya Ogan Ilir, 30862, Indonesia*
E-mail: leilydiaz@yahoo.com

* *Mechanical Engineering Department, Sriwijaya University, Inderalaya Ogan Ilir, 30862, Indonesia*
E-mail: marwanizk@yahoo.com

***Abstract*— Fuel oil used in the boiler is able to substitute with biodiesel. In lower blends, there are no engine modification needed, but some researchers recommended some technical adjustments in order to maintain the boiler's performance and equipment durability. This study consists of the comparison between the performance of boiler before and after retrofitting on the use of biodiesel. The diesel oil was introduced in biodiesel blends of 10% (B10), 20% (B20) and 25% (B25). A fire tube boiler was used for the test with pressure of 3 bar and heat input capacity of 60,000 kcal. The boiler retrofit is conducted by fine tuning the fan damper scale (FDS) and adding a heating feature on fuel system. It was specifically intended to maintain the quality of combustion and boiler efficiency as well as to avoid an increase in fuel consumption. The combustion behavior was monitored by exhaust emissions of CO, NOx, and SO_2. The fan damper scale (FDS) and fuel temperature is adjusted by the increasing portion of biodiesel used. The fuel heating apparatus was set at temperature of 40°C for the use of B10, and 60°C for B20 and B25. The FDS adjustment was successfully resulted a reduction in rate of combustion air by average of 9.2%. The boiler retrofitting for the utilization of B10, B20 and B25 showed an increase in boiler efficiency by 0.64%, 0.42% and 2.6% respectively. The boiler retrofitting is surprisingly reduced the fuel consumption by average of 11.2%.**

***Keywords*— biodiesel; boiler retrofit; fan damper scale; fuel temperature; fuel consumption**

I. Introduction

Boiler is one of industrial or commercial device which crucial for steam generation. The fuel used in boiler depends on the design and operating conditions. Boilers fuelled with oil fossil based is still dominated by commercial and or institutional sector, and a small portion is still used by industry sector. In order to reduce the dependence on petro diesel consumption, the utilization of biodiesel in blends with diesel oil has been mandated. The Indonesia government has targeted the use of biodiesel in the industrial and commercial sectors, namely 20% in 2020 and 25% in 2025.

It is still in concerns that the use of biodiesel in industrial devices is technically caused a compatibility problem. In higher blends, the use of biodiesel can potentially lead to decreased boiler efficiency and increased fuel consumption ([1], [6], [13], [14]). This condition is due to biodiesel has a lower calorific value. Palash [1] stated that the high blends of biodiesel in fuel can cause a decline in the ignition temperature of combustion chamber. It causes a reduction in firing rate which is impacted to the efficiency level.

The main cause of boiler inefficiency is heat loss, and upgrading the controls is one of the most effective ways to recapture lost heat in an existing system [9]. The use of biodiesel will lead to loss in engine power mainly due to the reduction in heating value of biodiesel compared to diesel, but there exists power recovery for biodiesel engine as the result of an increase in biodiesel fuel consumption [13].

Biodiesel contains approximately 11% oxygen by weight, which accounts for its lower heating value and lower volumetric energy content. NREL [9] gives the energy of biodiesel (B100) as roughly 8% less than diesel No. 2. Biodiesel blends of B20 and lower typically result in observable power loss or lower in fuel economy [9].

Boiler retrofit is defined as an activity to add new technology, spare parts and certain equipment’s to the existing boiler system for a particular purpose. Boiler retrofitting involves adding new technology, parts, and equipment to an older boiler system. Boiler retrofit generally intended to restore the boiler to suit the design and to improve return performance decreases. In America and Europe, retrofit projects are generally based on an increase in fuel consumption and efficiency demands of the tool according to the rules [12].

Fan damper is a feature in burner system which has a valve to control the movement of the air before it enters the cylinder combustion chamber. In the modern burner technology, fan damper also serves to reduce the incidence of wasted heat and improve the overall warming. Ghorbani [4] stated that the intake air control can cope with the decline in the efficiency of the engine due to the use of biodiesel. Fuel injection pressure associated with the combustion air supply and exhaust gas temperature, it affects the lost heat that occurs so that the impact on the efficiency of the appliance. Biodiesel combustion is more effectively occurred under conditions with low excess air [5]. Rahman [10] suggested the control of combustion air in the boiler fuelled with biodiesel can be made by adjusting fan air inlet valve (fan damper scale).

Fuel heating is applied to control the adverse effects due to the increased viscosity of biodiesel blends. In this condition, fuels more easily injected into the combustion chamber due to the forming grains finer mist. In this condition, the fuel is easily achieve the ignition conditions so that the combustion preparation period becomes shorter and the fuel consumptions become less. The effects of fuel heating can potentially keep the combustion chamber temperature in high. It is convinced to control the potential decrease in adiabatic flame temperature.

The biodiesel blends utilization is such urgent. To apply effectively in boiler, it is necessary to avoid any potential risks in some technical efforts. The boiler retrofit is applied to anticipate some technical problems and the adverse effects on the performance and operating life of the boiler caused by the changes of fuel characteristics. In this research, it will be compared the performance of the boiler on business as usual (BAU) conditions with the boilers that have been retrofitted.

II. Methods

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In this study, the biodiesel blends were tested in a fire tube boiler with pressure of 3 bar. Biodiesel blends portions are varied with 10%, 20%, and 25% or named by B10, B20 and B25. The boiler operation variable is combustion fan damper scale (interval 4.0 to 5.0) and fuel temperature (40-70 ° C). The biodiesel used in the test was based on palm oil with characteristics as shown in Table 1.

TABLE I
The Characteristics of Biodiesel and Diesel Oil

parameter	units	B0	B100
viscosity @40°C	mm^2/s	2,96	4,52
density @15°C	kg/m^3	822,4	874,80
calorific value	MJ/lb	46,8	39,45
cetane number	-	47,4	67,2

The boiler set and fan damper tools are shown in Figure 1. The boiler performances which evaluated in the study are boiler efficiency and fuel consumption. The analysis of combustion products is measured by a gas analyzer type of IMR 1400 which is installed on the boiler chimney. Boiler efficiency is calculated by indirect method or heat losses method. The operating conditions used in the tests are presented in Table 2.

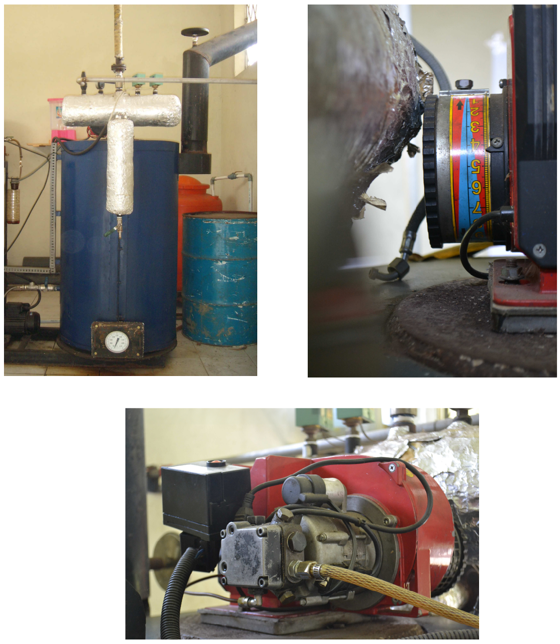

Fig. 1a. Fire Tube Boiler (1b) Burner, (1c). Fan Damper Scale

TABLE II
Operating Conditions of The Fire Tube Boiler

Parameter	units	Value			
		B0	B10	B20	B25
Ambient temperature	°C	28 - 32			
fan damper scale	-	4.6	4.6	4.3	4.0
load mode	%	100	100	100	100
duration	minute	60	60	60	60
Fuel temperature	°C	30	40	60	60

The boiler is operated with fan damper scale of 4.6 in condition of business as usual. It is showed that the amount of air is set constant despite changes in the composition and characteristics of the fuel.

In this study, a simple installation is added to the fuel system with oil heater. The fuel tank equipped with a stirrer, which is operated in particular at higher blending of biodiesel (> 20%). This features is set to avoid shocking response on the burner system and keep the heating temperature homogeneity in the fuel tank.

III. Results and Discussions

Boiler efficiency simply shows the comparison of energy used that leaves the system against chemical energy of fuel entering the system. In the conditions of a business as usual (non-retrofit) it is known that the higher blend biodiesel used causing a decrease in efficiency and an increase in fuel consumption increased as shown in Figure 2. Compared to petroleum diesel, the use of biodiesel in blending of 10-25% lead to an increase in heat loss of 9.71%. The losses caused a decrease in efficiency in average of 1.39% while the condition is connected with an increasing in exhaust gas temperature by an average of 5.96%.

The higher blends of biodiesel is identical to a higher content of oxygen in the fuel. It means, in BAU case, the biodiesel blends combustion occurred in the same quantity of combustion air. It probably caused a decrease in adiabatic flame temperature as well as a reduction in rate of heat transfer. The more excess air in BXX combustion caused an increase in the amount of exhaust gas per unit fuel. This conditions lead to a higher heat loss in dry flue gas, and necessarily caused a decrease in efficiency.

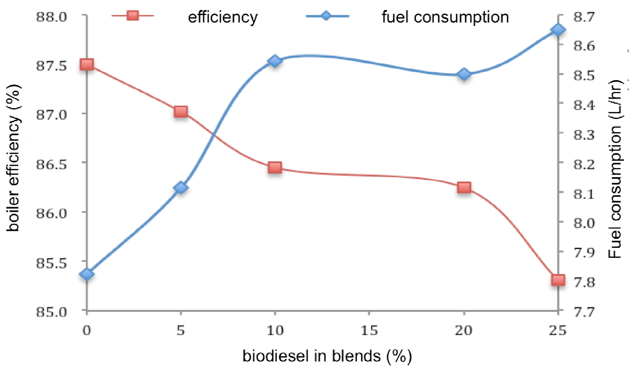

Fig. 2. Effects of BXX use on boiler performance at Business as Usual (BAU) condition

The value of heat loss through the exhaust gas (dry) increased by an average of 0.71% with the increasing of biodiesel content in fuel. It can be explained that combustion air entered into the burner system at ambient temperature (between 28-32 °C) and leave the boiler at a high temperature (98-124 °C). From several of tests, [2] concluded that in every 3.4% increase in oxygen content in the exhaust gases, it related to a combustion with high excess air. It directly caused a decrease in adiabatic temperature up to 260 ^{o}C.

In the same volume of fuel and combustion condition, a fuel blend with a lower calorific value requires more mass of fuel to complete the combustion process. The higher viscosity of the fuel affects the injection phase, thus affecting the injection pressure on the burner. It can followed by a decrease in engine power. The process consumed more fuel in order to achieve the optimal combustion conditions. In this study, the boiler operates with the same amount of combustion air and operated at full load mode, so that an increase in fuel viscosity and density affect the increase in fuel consumption as well.

Based on the analysis of residual oxygen in the exhaust gases, the amount of excess air supplied to burner on fan damper scale of 4.0, 4.3 and 4.6 were respectively 71.13%, 85.54% and 119.37%. The amount of excess air is influenced by setting the burner injection pump which operates with fuel rich mode. In order to achieve complete combustion, the amount of excess air required is greater than theoretical air requirements.

On the use of 10-25% biodiesel in blends, FD scale adjustment means a reduction in excess air at average of 9.2%. It related to an increase in boiler efficiency of 1% by average. This e is accompanied by a decrease in exhaust temperature 7.67 °C (45.8 ^{o}F) by average. According to the Bureau of Energy Efficiency [3], for each percent of boiler efficiency increase, it can be achieved by a reduction in excess air by 15% and a decreased in exhaust gas temperature 40 °C.

The effects of biodiesel blends use on the fuel consumption in variation of fuel temperature are presented in Figure 4. The fuel consumption measurement found lower in each fuel blends over a range of heating fuel of less than 65^{o}C. A further heating can potentially cause an fuel overpower due to very low viscosity.

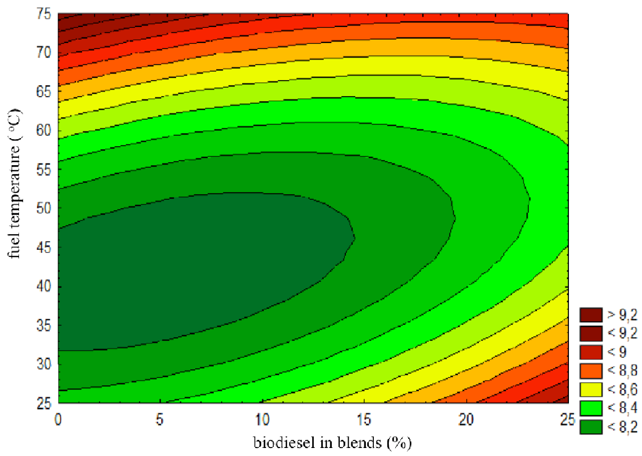

Fig. 3. Effects of Fuel Heating Temperature to Fuel Consumption

The performance comparison between boiler with BXX in BAU conditions and retrofit conditions are presented in Table 3.

TABLE II
BOILER PERFORMANCE COMPARISON

Fuel Blends	Boiler in BAU condition		
	FD Scale	efficiency (%)	Fuel consumptions (L/hr)
B10	4.3	86.45	8.55
B20	4.0	86.25	8.50
B25	4.0	85.31	8.65
Fuel Blends	Boiler Retrofit		
	FD Scale	efficiency (%)	Fuel consumptions (L/hr)
B10	4.3	87.19	8.08
B20	4.0	86.98	7.98
B25	4.0	85.68	8.26

The combustion requires less air compared by a higher blends of biodiesel used. A high value in Fan Damper scale (FDS) is indicated a higher rate of air entering the combustion chamber. On the use of B10, FDS adjustment was set from scale of 4.6 to 4.3. It led to an increase in efficiency of 0.64%. When B20 used in boiler, FDS is adjusted from of 4.6 to 4.0, which resulted an increase in efficiency of 0.42%. Meanwhile, the use of B25 showed the highest efficiency increase, i.e. 2.6%. It is achieved when the FDS was changed from 4.6 to 4.0. FDS adjustment equivalent to the effort of reduction in excess air of 9.2% per scale point.

In boiler retrofit mechanism, the optimum fuel temperature for the use of B10, B20 and B25 is respectively 40^{o}C, 60^{o}C and 60^{o}C. The fuel heating for each blends contributed to the reduction of fuel consumption of 11.34%, 11.94% and 10.31%.

IV. Conclusions

The use of biodiesel blends can be carried out effectively in boiler with the mechanism of boiler retrofit. The techniques of retrofitting are by adjusting the amount of combustion air through fine tuning of fan damper scale and adding some instruments to the heating fuel system.

The changes in boiler operating conditions is successfully performed an increase the boiler efficiency in average of 1.46% and a decrease in fuel consumption in average of 11.19%. This result indicates that the boiler retrofit can potentially overcome the problem in decreased efficiency and increased fuel consumption. At the optimum conditions, boiler retrofit mechanism can be applied to achieve a better boiler performance compared to boiler fuelled with diesel oil on business as usual conditions.

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