Abstract— The use of biodiesel have been tested on some combustion devices extensively, including on the boiler. Biodiesel blends use in boiler is possibly affected the behaviour of combustion. It can be evaluated by analysing the exhaust gas composition and temperature. This study is conducted to show the distribution of temperature in the combustion chamber and boiler stack’s using Computational Fluid Dynamic (CFD) software Fluent. Experimentally, the tests carried out on the fire tube boiler vertical type cylinder with pressure of 3 bar. Temperature measurement is performed at three points in the combustion chamber and boilers’ stack using optional thermocouple and gas analyser IMR 1400. The biodiesel used in the tests is palm oil based with blending portion varies from 5-25%. The results show that in the higher blend of biodiesel, the temperature of combustion chamber tend to be lower but the exhaust gas temperature at the end of the chimney was likely to increase. On the other hand, the simulation using Fluent showed the pattern of temperature distribution was relatively equal between the use of biodiesel in the blends under 25% compared to the use of diesel (B0).

Keywords— biodiesel; boiler; combustion; CFD; temperature distribution

I. INTRODUCTION

Boiler is industrial equipment which is used for steam production. Steam can be used for heating agent or movement energy. The heat comes from combustion of fuel which is done in Boiler.

Depletion of world oil reserves and combustion effect of fossil fuel support the use of alternative energy. Biodiesel is one of alternative energy which is could be used for reduce dependence of fossil fuel. Compared with conventional diesel oil such as solar, biodiesel known as green energy, renewable, and have clean exhaust gas composition. Biodiesel and solar blend in varies portion can be used directly without machine modifications [1].

Complete combustion reaction produces CO₂ and H₂O. Problem which is often encountered in boiler performance is incomplete combustion. To have a complete combustion, highy and uniform temperature of combustion chamber were needed. High temperature can be achieved from complete combustion, while uniform temperature depend on heat transfer in combustion chamber. This heat transfer will be affected temperature distribution in combustion chamber and boiler stack.

One of the effort that used to know temperature distribution, oxygen required and combustion products resulted such as CO₂ and H₂O is CFD (computational fluid dynamic). CFD is a fluid dynamic analysis in a system by using algorithm numeric method based on computer [2]. Reference [2] worked on gas combustion that resulted from biomass gasification in premixed gas burner by 3D computational fluid dynamic method. He found the increased air flow rate would be reduced temperature and shorted flame. This caused by the amount of air would be added excess air.

Syukran [3] described the utilization of CFD program to evaluate temperature distribution in combustion chamber of boiler 51 MW by using MFO (medium fuel oil) and LNG (liquiefied natural gas). He reported the average temperature distribution in boiler relatively equal to maximum temperature of MFO and LNG from 1500 to 1700°C. Small differences occured in outlet of boiler that caused by material flowrate differences, inlet MFO greater than LNG.

Studied performance of oil burner system utilizing various biodiesel blends [4]. They elaborated the enhancement of biodiesel in blends would be reduced temperature in large amount. Enhancement of biodiesel in blends declined calorific value of fuel.

Nayak and Pattanaik [5] also reported impact of biodiesel on combustion, performance and exhaust emissions of diesel engines. These author found machine that used B100 as fuel resulted small exhaust gas temperature compared to solar. This showed biodiesel have longer initial combustion and expansion mass.
A review on combustion, performance, and emission characteristics of fuels derived from oil seed crops (biodiesels) was investigated by Gopinath et.al [6]. They analyzed biodiesel combustion characteristics almost similar to diesel. However, performance of biodiesel slightly lower than diesel. Biodiesel produced more nitrogen oxide, while carbon monoxide, hydrocarbon, and smoke emission in comparable value with diesel.

In this research we report temperature distribution in boiler which is used solar-biodiesel blends as fuel with 5%, 10%, 20% and 25% biodiesel added.

II. MATERIAL AND METHODS

We simulate fire tube boiler with dimensions as follows:

a. Air channel : 4 cm x 10 cm
b. Fuel channel : 0.5 cm x 20 cm
c. Burner : 25 cm x 20 cm
d. Flame tube : 30 cm x 100 cm
e. Distance of tube to boiler base : 20 cm
f. Fire tube : 10 cm x 70 cm
g. Initial stack : 20 cm x 40 cm
h. Middle stack : 20 cm x 70 cm (slope 30o)
i. Final stack : 20 cm x 40 cm

This simulation is done by software Fluent. Model of completions are:

a. Steady state
b. Heat transfer
c. k- epsilon RNGturbulence
d. Species transportorgas combustion
e. Reaction measurement by Eddy dissipation model

In this study numerical analysis are given by mass, momentum, and heat conservation equations as follows:

\[
\frac{\partial p}{\partial t} + \nabla \cdot (p\mathbf{V}) = 0 \tag{1}
\]

\[
\rho \left[ \frac{\partial \mathbf{V}}{\partial t} + (\mathbf{V} \cdot \nabla) \mathbf{V} \right] = -\nabla p + \mu \nabla^2 \mathbf{V} + \rho f \tag{2}
\]

\[
\rho c_p \left[ \frac{\partial T}{\partial t} + (\mathbf{V} \cdot \nabla) T \right] = h \nabla^2 T + q \tag{3}
\]

With steady state assumption, \(\partial/\partial t\) at the equations will be eliminated. After modelling the process, boundary condition will be determined as follows:

a. Air injection velocity 0.05 m/s
b. Fuel velocity : B0 0.003 m/s, B5 0.0029 m/s, B10 0.0027 m/s, B20 0.0023 m/s dan B25 0.0018 m/s.
c. Exhaust gas temperature: B0 382 K, B5 378 K, B10 376 K, B20 360 K dan B25 354 K.
d. Fuel temperature 300 K and air temperature 303 K.

III. RESULTS AND DISCUSSION

A. Fuel Characteristics

The purpose of enrich cement of fuel quality is to develop quality of combustion. One way to get that is using alternative fuel, such as biodiesel. Diesel oil has physical and chemical properties that can effect its combustion. One of the properties is heating value of C, H, N, O, and S.

| Parameter | Unit | B0 | B5 | B10 | B20 | B25 |
|-----------|------|----|----|-----|-----|-----|
| Carbon    | %    | 84.15 | 83.76 | 83.36 | 82.58 | 82.19 |
| Hydrogen  | %    | 12.67 | 12.62 | 12.58 | 12.49 | 12.44 |
| Nitrogen  | %    | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  |
| Oxygen    | %    | 2.93 | 3.39 | 3.85 | 4.76 | 5.22 |
| Sulphur   | %    | 0.1  | 0.095 | 0.09 | 0.08 | 0.075 |
| Heating Value | MJ/lb | 46.8 | 46.467 | 46.133 | 45.467 | 45.135 |

Report in [7]
Fuel analysis is used to determine pollutant emission, such as amount of carbon, sulphur, oxygen, and hydrogen in fuel that will be burned.

B. Effect of Biodiesel Addition to Combustion Chamber and Stack Temperature

Biodiesel is methyl ester or ethyl ester compound which is used as an alternative fuel for fossil fuel substitution. The advantages of biodiesel are comes from renewable source, clean combustion so it doesn’t contribute carbon dioxide enrichment, and good for environment [8].

Combustion is a fast process or oxidation reaction between fuel and oxidator agent that caused flare and heat. To execute combustion, calorific value is needed to evaluate. Amount of calor required says as calorific value. Combustion reaction:

\[ C_{x}H_{y} + aO_{2} \rightarrow bCO_{2} + cH_{2}O \]

Combustion is a mixing between fuel and air. Complete combustion is effected by turbulence of inlet air flow. If turbulence was increased, distortion of fire absorption will be increased flare temperature [9].

| Parameter | Unit | B0  | B5  | B10 | B20 | B25 |
|-----------|------|-----|-----|-----|-----|-----|
| *T_1      | K    | 800 | 788 | 778 | 773 | 700 |
| **T_2     | K    | 593 | 588 | 583 | 573 | 498 |
| ***T_3    | K    | 382 | 378 | 376 | 376 | 354 |
| Laju fuel | m/s  | 0.003| 0.0027| 0.0025| 0.0022| 0.018 |

* T_1 = Combustion Chamber temperature
** T_2 = Initial stack gas
*** T_3 = Final stack gas

Commonly heat transfer in the boiler occurs through radiation, convection, and conduction. Radiation appears between flame and firewall. Radiation energy depends on number of surface heat absorption that exposure by flare. In convection, heat transfer occurs between flue gas and firewall. Finally, in conduction, heat transfer exist through firewall to the air [3].
The highest temperature occurs in the inlet of the combustion chamber. Fire starting to grow in this burner zone, because of fuel-oxygen mixing. After that, temperature decreases through the fire tube to the final stack of the boiler. This is caused by the fire tube wall heat absorption, so that heat will be absorbed by the fluid (water).

In flame tube area, flue gas with high temperature from 2370 °K to 2130 °K tends to reach the wall. This is caused by burner construction as inlet for fuel and air. The type of burner used is Monarch Oil Burner 1-3. At modelling, suitability between actual burner construction and model is very difficult to get. So, the pattern of distribution temperature through the burner will be affected.

Flue gas temperature profile through the flame tube tends to deplete. This is caused by the transfer firewall heat absorption to fluid. For solar, temperature reduces from 2370 °K to 611 – 1340 °K. However, for biodiesel, temperature reduces from 2140–2130 °K to 576 – 131 °K.

Simulation doesn’t show the form of the fire, but describes the distribution temperature which is occurred as combustion effect. In temperature contours, maximum temperature is relatively equal. Only small differences will be visible between them.

One of the factors that affect temperature is the ratio of fuel-air for combustion, while the ratio of solar-biodiesel blends (BXX) doesn’t affect to temperature distribution. BXX defines as mix of biodiesel and solar, such as B20 which is consist of 20% biodiesel and 80% solar.

Higher biodiesel percentage will be increased viscosity. Viscosity of each blend has differences, so that in this research fuel velocity is made in varies. Besides that fuel doesn’t preheat so fuel velocity is determined by viscosity value.

### IV. CONCLUSIONS

There is no significant temperature change in combustion between B5, B10, B20, B25 and B0 (Solar). It means biodiesel addition doesn’t affect temperature profile, so the highest portion of biodiesel (25%) can be used for boiler fuel.

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