Experimental Study on A Single Droplet Combustion of Plastic-Pyrolysed Fuel and Kerosene Blended

LUKAS KANO MANGALLA*), R. PANGARA, ADITYA RAHMAN
Mechanical Engineering Department
Halu Oleo University
Jl. HEA Mokodompit Anduonohu Kendari 93232
INDONESIA

YULIUS B. PASOLON
Agricultural Department
Halu Oleo University
Jl. HEA Mokodompit Aduonohu Kendari 93232
INDONESIA

*) *E-mail*: lk.mangalla@gmail.com

Abstract: - Plastic-pyrolysed fuel is expected to be an alternative fuel to the oil fuel in many combustion applications including boilers and furnaces. However, some properties of the fuel are completely different with other established fuels on the market like diesel oil, kerosene and gasoline. Blended with the base fuel is supposed to improve the properties and enhance the combustion performances for several industrial applications. This study aims to investigate the combustion phenomena of a single droplets fuel from plastic pyrolysed fuel and kerosene blended. Droplets fuel evaluated in this study consist of 0%, 10%, 20% and 30% K/P respectively, (K/P stands for Kerosene and Pyrolysed Fuel compositions). The droplet of each composition produced from small injector was evaluated in the small chamber at room temperature dan pressure. Distribution of droplet diameter during combustion was recorded and later analyzed using Image-J software. Temperature of the chamber during combustion was measured using K-Type thermocouple at around 2 mm from the tip of injector. Result of the analysis indicates that the more kerosene added to plastic-pyrolysed fuel the less the time to burn the droplets and the lower the temperature achieved.

Key-Words: Evaporation, Combustion, Droplet distribution, Kerosene and Plastic-pyrolysis Fuel.

1. Introduction

In the recent years, the policy on energy security and sustainability is strongly required as well as environment concern. According to World Energy Outlook 2011 [1], Global energy demand will increase significantly until 2035. The oil demand was predicted to increase about 18% at that time and, as the effect of the fuel used, the CO2 emission would be predicted to rise around 20%. Therefore, A high efficiency of combustion techniques must be developed to produce high energy saving and low pollutant emission of the engines. A complete combustion of fuel in the engine depends primarily on the ability of the fuel system mixed with air (as an oxidant) in the combustion chamber.

Liquid fuel is usually introduced into the combustion chamber as the spray droplets, that is later experiencing some sequence processes to produce heat. Combustion processes of the droplet fuel in a combustion chamber involve some physical and chemical properties of the fuel. Fuel atomization and evaporation is essential steps in combustion engineering applications. Spray of fuel must be evaporated immediately after injecting into the combustion chamber for a better energy conversion. Air fuel ratio inside the chamber depends on the evaporation rate, diameter and the velocity of the individual droplets [2].

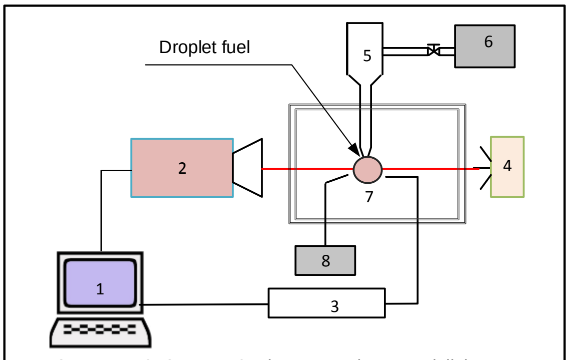
Evaporation characteristic of the droplet fuel can vary depend on the size, surface temperature, surface tension and fuel density and gas diffusion on the individual droplet [3]. In this study, evaporation of a single droplet fuel from plastic-pyrolised fuel and kerosene blended was investigated experimentally under atmospheric temperature and pressure. Plastic pyrolized fuel used on this analysis is the hydrocarbon derived fuel resulting from pyrolysis process of polyethylene (PE) plastic. Pyrolysis process is a thermal process that usually heats the plastic material inside the plastic reactor at a temperature of 250-500^oC [4]. High reaction temperature and heating rate can promote the significant production of light hydrocarbon that has a high heating value.

A lot of studies have been conducted to analyze the atomization and evaporation of alternative fuel at different temperature and pressure. Zhang, et.al., [5] investigated spray characteristics of gasoline, methanol and ethanol fuel using Mie scattering and Laser Induced Fluorescence. They analyzed the effect of ambient pressure and fuel temperature on the distribution of liquid spray and found that the high temperature of the fuel can improve spray atomization, evaporation and distribution. This phenomena can provide better combustion of the specified fuel. Investigation on heat and mass exchange of the spray fuel is important specially for small droplet fuel [6]. Combustion processes in a heterogeneous fuel differ greatly from that in homogeneous fuel because they are governed not only chemical but also physical processes of combustible mixture formation, such as atomization evaporation and diffusion mixing of the fuel vapor and an oxidizer [7].

Several studies on evaporation of the fuel droplet use the assumption of a quasy steady of gas-phase surrounded the droplets and temperature. This assumption can solve the evaporation rate using D^2-law which describes the unique phenomenon that droplet decreases its diameter linearly with the time in the high temperature environment. In this research combustion of the droplet fuel is conducted at room temperature and pressure.

2. Methods

An experimental measurement was conducted to analyze the combustion characteristics of the single fuel droplets from plastic-pyrolyzed fuel and kerosene blended. Layout of the experimental setup can be seen in Fig.1. A new model of droplet combustion was developed for a simple monitoring



1. Computer, 2. Camera, 3. Thermocouple, 4. Back light,
5. Injector, 6.Fuel tank, 7.Combustion chamber, 8. Heat source

Fig. 1. Layout of experimental setup

of droplet distribution and temperature during the combustion process.

2.1. Materials

The primary material used in the study is both of the pyrolysis fuel from plastic waste and kerosene fuel. Plastic pyrolised fuel was derived from pyrolysis proses of plastic PE waste material in the developed reactor, Tripod Pyrolysis Reactor.

Tabel 1. Properties of fuel

Properties	Plastic-pyrolysed fuel	Kero-sene	10% K/P	20% K/P	30% K/P
Density (kg/L)	0.726	0.805	0.734	0.743	0.753
Viscosity (cP)	0.941	0.98	0.901	0.889	0.887
HHV (MJ/kg)	46.116*	43	NA	NA	NA

*Source : Ref [8]

2.2. Procedure

Pyrolysed fuel from plastic is the main fuel used in this analysis. Kerosene added to the main fuel and later mixed in the various of volume the blended. In this study the compositions of pyrolysed fuel (P) and Kerosene (K) are vary from 0%, 10%, 20% and 30% K/P respectively. Each composition was put in the injector and applied a small forced to produce droplet fuel. A small diameter of injector (around 0.2mm) was used to produce droplets. Droplets diameter produced from the injector are varied from 0.5 mm to 1.5 mm. It was the challenging to produce same diameter droplets in this study.

Combustion process of the droplets was performed at room temperature (27^{o}C) and pressure (1 atm). Each droplet fuel produced on the tip injector was later ignited using a heat source from a battere. Diameter distribution of droplet fuel was recorded using a high speed camera with a back source of light. Combustion experiments of each fuel composition were conducted 5 times at same treatment conditions. Distribution characteristic of droplet diameter can be analyzed from imaging system recorded on this device. Temperature of combustion chamber was also measured around 2 mm from the tip of injector using K-Type thermocouple. Measurement data on this device were connected with a computer for an easy processing and analyzing.

Image-J software was used to analyze droplet diameter distribution of the fuel droplets. For the purposes of determining droplet size during the combustion time, the threshold value was adjusted to distinguish between background noise of the picture and the picture of fuel droplet. Binarization of the droplet diameter in specified time was performed to define area of circularity edges of the images thresholded. Size diameter of the fuel droplet was measured at each 0.5 sec during combustion proces.

3 Results and Analysis

Burning characteristics of several composition of the droplets can be seen in Fig. 2. Spatial and temporal distribution of the flame contours vary with the droplets compositions. The figure shows that the pure pyrolyzed fuel (0% K/P) has longer time of combustion followed by 10%, 20% and 0% K/P respectively. Higher value of viscosity and heating value of the fuel may affect the fuel evaporation and combustion as shown in the flame structure. The shape and distribution of the flame depends on many factor such as gas-phase stream around the flame and energy content of the droplets fuel.

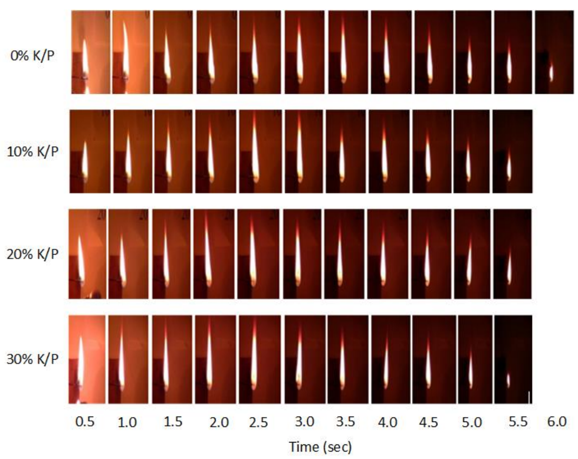


Fig. 2. Burning characteristics of the fuel droplets at several times after ignited

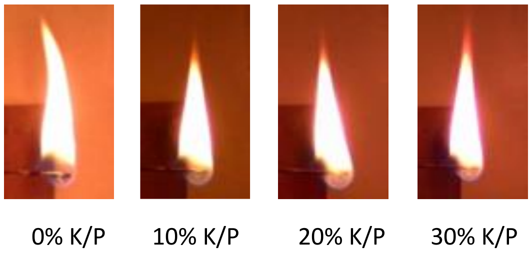


Fig. 3. Flame comparison of the fuel droplets at 1.0 sec after burning.

Fig. 3 compares the flame contours of several droplets fuel at 1.0 sec after burning. It is the evidence that pyrolized-fuel droplet (0%K/P) has a higher flame than another composition of the droplets. However, for the next composition the higher the kerosene in the droplets the brighter and the higher the flame appearent. It can be seen also in Fig.1 that in the early burning of the droplets, higher kerosene content produces higher flame structure.

Fig. 4 shows the temperature characteristic of droplets fuel during combustion in a quasi-steady environment. As seen in the figure, the temperature of the fuel increases rapidly after ignited around 5 sec after heating and reaching maximum of 527 K, 506 K, 458 K and 431 K for droplet composition of 0% K/P, 10% K/P, 20% K/P and 30% K/P respectively. Droplet of pyrolyzed-fuel seems having a little higher in temperature than another composition of droplets. It migh be happened due to the heating value and density of the fuel which is higher than other compositions.

An expected trend that droplets diameter reduction of pure pyrolysed-fuel would be lower than mixed fuel droplets. The higher the kerosene in the droplets the higher the droplets diameter reduction. This phenomenon may indicate that high composition of kerosene can improve the evaporation rate of the droplet and affects the burning rate. Fig. 5 presents the ratio of droplet diameter distributions (d^2/do^2) versus time of combustion for the four different compositions of the fuel. The distribution of diameter reducing is proportional to the time of combustion as the phenomenon happened when the droplet fuel is burning [9]. The trend happened in this low temperature and pressure environment is almost similar to the behavior of droplet combustion happened at elevated pressure and temperature environment. When the temperature of gas phase around the droplets is high enough, as shown in Fig. 4, the evaporation of droplet become increasing and the droplet diameter reduces rapidly. Heat transfered from the surrounded gas is spent on evaporation of

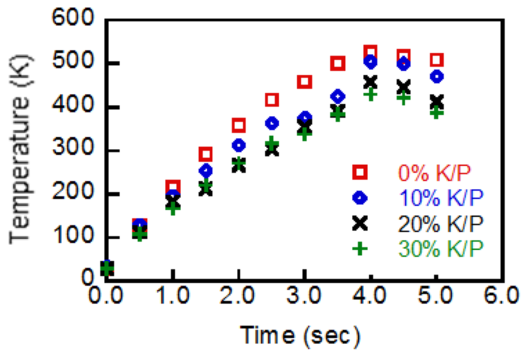


Fig. 4. Temperature around the droplet inside combustion chamber.

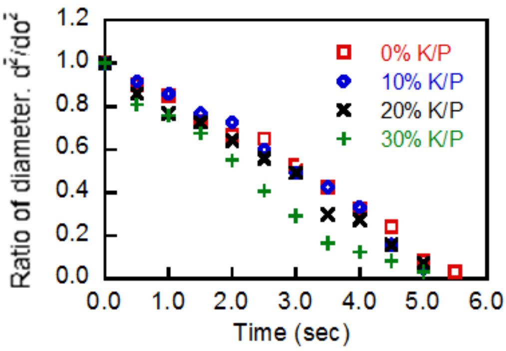


Fig. 5. Droplet reduction characteristics during combustion.

the fuel as explained by Kasachkov [10]. It can be seen also in the figure that evaporation of the droplets fuel increases with composition of kerosene but enenrgy released decreases.

4. Conclusion

An experimental study has been conducted to analyze the combustion characteristics of the single fuel droplets of plastic-pyrolyzed fuel and kerosene blended. The result of the study shows that addition of some kerosene on the fuel blended can improve properties and later enhance the combustion performance of the fuel droplets. It is the evidence that distribution diameter of droplets is reduced with composition of kerosene in the droplet and made the droplets burned faster, however, the energy released become lower. The evaporation rate and energy released must be taken into the consideration on this blended fuel.

An advanced experimental and simulation studies is needed for analyzing the fuel evaporation phenomena inside the chamber as well as the fuel burning performances during combustion. Further study is also proposed for higher injection pressure and temperature condition of the fuel.

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