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ANALYSIS OF THE HEAT RELEASE RATE OF LOW-CONCENTRATION BIOETHANOL FROM SAGO WASTE

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ABSTRACT

This study aimed to analyze the heat release rate from the combustion process of bioethanol from sago waste to determine the viability and feasibility of low-concentration bioethanol as an alternative fuel. The heat release rate, exhaust gas, and flame temperature were measured using a cone calorimeter, and bioethanol combustion was conducted using the pilot ignition method, with an ethanol quality range of 60–70%. The analysis that the heat release rate of 60% bioethanol combustion ranged from 20 to 140 kW/m^2, while a lesser range resulted from 70% bioethanol combustion (18–45 kW/m^2). The flame temperature for 60% bioethanol was found to be 440°C, while the smoke and orifice temperature was 150°C. The combustion of 70% bioethanol produced a flame temperature of 450°C and a smoke and orifice temperature of 120°C after approximately 6 min of combustion. This study contributes a solution for meeting the energy demand in rural areas, where the access to and availability of major fuel resources are limited. In addition, from the obtained results, this research concluded that bioethanol made from sago waste is suitable as a clean and alternative fuel for household applications in rural areas.

Keywords: Flame temperature; Heat release rate; Low-concentration bioethanol; Sago waste

1. INTRODUCTION

Currently, the need to reduce the use of fossil fuels is an important concern. Alternative energy sources need to be developed, and bioethanol is one type of alternative fuel. Indonesia has major potential for developing renewable energy resources, especially in the province of Papua, but this has not been utilized in the best way possible. One solution for the development biofuels is to use bioethanol made from waste residue from sago production, which usually remains unused and ends up as waste (Dhiputra et al., 2015). Bioethanol is a biofuel produced from plants containing starch or cellulose components (Flach, 1997). Thus, one possibility is using sago dregs as bioethanol for an alternative fuel source to fulfill the energy demand in our country, especially in rural areas. The sago potential in Indonesia is ±1,250,000 ha, with ±1,200,000 ha in Papua, making it the area with the greatest potential for sago fuel use in the world.

The general problem of this study is related to energy needs in the region, the availability of

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energy, and access to distribution of energy to the region, especially in Papua. Because of its geographical position, it is difficult to provide sufficient fuel to fulfill the daily needs in Papua community. Renewable energy can serve as an energy development solution capitalizing on the existing potential in the region, namely the development of biofuels from available components like bioethanol (Rajvanshi et al., 2007).

Sago wastes that are no longer in use are studied in this research as bioethanol fuel (Awg-Adeni et al., 2013). Specifically, Papua's sago waste can be used for household energy needs. Sago palms are extremely prolific, as every tree can produce about 200–500 kg of wet sago starch per day; this represents 72–180 tons per year. The daily waste from sago dregs produced 38-90 tons per year and sago waste from residual production can be utilized as bioethanol fuel (Haska, 2008). Bioethanol produced from waste sago dregs via fermentation technology shows a good ratio of 4:1; that is, 4 kg of sago dregs can produce 1 L of bioethanol. Thus, each day, 10–23 kL of bioethanol can be produced, and this fuel can be used as a replacement for fossil fuels in remote areas, such as Papua, Indonesia.

The present research was carried out to facilitate the development of an alternative choice that has high potential as an alternative energy substitute for fossil fuels in the household fuel needs in rural areas of Papua. Bioethanol (C_2H_5OH) is renewable and environmentally friendly; moreover, it produces lower carbon emissions compared to kerosene, gasoline, and so on (up to 85% lower). Ethanol is a polar liquid that can be mixed with water, other alcohols, esters, ketones, ethers, and most organic solvents (Micky et al., 2015). Generally, bioethanol has a special affinity to carbon dioxide and hydrogen sulfide. The boiling point of bioethanol is 64.7°C, pour point and flash point of bioethanol fuel is–239.03 kJ/mol at 25°C. However, in terms of its production value, low-content bioethanol fuel (60–70%) is still relatively expensive; thus, it is only suitable for remote areas. This low-level bioethanol can be applied with the necessary engineering stove combustion chamber in accordance with the characteristics of the fuel itself. Bioethanol from sago waste also has better characteristics than petroleum fuel because it can improve combustion efficiency and its combustion is clean burning and environmentally friendly.

Flames formed in the combustion process represent a phenomenon that occurs in the gas phase; hence, the burning flame on liquid fuels must be preceded by a phase change process that turns liquid fuel into gas. In case of incomplete combustion, products of combustion will produce a CO_2 and H_2O, but it will instead form unsaturated hydrocarbons, formaldehyde, and sometimes carbon. At extremely high temperatures, the gases burst or dissociate into complex gases, and the molecules of the base gas will be split into atoms; these float on the surface of the gas phase and into the fire, causing an increase in temperature. Gas and steam resulting from thermal decomposition will mix with oxygen or air as an oxidizer to form a flammable mixture. This represents an endothermic reaction, and dissociation depends on the temperature and time of contact (Choi & Chung, 2010).

The heat release rate (HRR) can be defined as the production rate of heat released per unit of time in a cone calorimeter using bioethanol fuel that produces an exothermic combustion reaction after the activation energy is exceeded. The HRR function is a quantitative parameter of combustion events that can be measured (kW/mw). This research involves an analysis of the experimental combustion of bioethanol at low concentrations of 60% and 70% using a cone calorimeter and the pilot ignition method to evaluate the HRR and the temperature of the flame, as well as to study the nature of sago waste bioethanol fuel in terms of whether or not it is viable and feasible as fuel (Babrauskas, 2002). A complete (stoichiometric) combustion reaction reaction between an ethanol fuel and hydrocarbon materials can be formulated theoretically through Equation 1, which was developed as follows by Strehlow (1985) in his stoichiometries combustion practical fundamentals:

$$C_2H_5OH + 2\ (O_2 + 3,76\ N_2) \rightarrow 2\ CO_2 + H_2O + 7.52\ N_2 \qquad (1)$$

The combustion reaction is a reaction of complete (stoichiometric) combustion wherein the hydrogen and carbon in the fuel content of 60–70% C_2H_5OH oxidizes entirely into H_2O and CO_2. Equation 1 also shows that every 0.7 kmol kmol of air in the atmosphere contains 0.79 kmol of nitrogen and 0.21 kmol of oxygen. The burning application is carried out on a cone calorimeter to measure the rate of heat production, burning time, variety of time reduction, and the production of smoke from bioethanol fuel.

This research aimed to analyze the HRR from the bioethanol combustion process using sago waste to determine the viability of low-concentration bioethanol as an alternative fuel. The parameter values obtained in these experiments are: HRR, flame temperature, exhaust gas temperature, and smoke temperature.

2. EXPERIMENTAL SETUP

The experimental setup was carried out using a cone calorimeter to measure the HRR and test the exhaust gases from bioethanol combustion using a corn residue gas analyzer as a tool for quantitatively measuring gas combustion products. The research was conducted using a cone calorimeter, which was equipped with thermocouples so that the HRR calculation could be performed simultaneously with the measurement of the temperature of the flame. Before the data from the cone calorimeter could be retrieved, preparation for the equipment unit of the cone calorimeter was carried out according to the guidebook for using the cone calorimeter by (Babrauskas, 2002), to ensure that the data captured were accurate. A cone calorimeter is a device used to study fire behavior. In the liquid phase, ethanol fuel reacts with atmospheric air. The cone calorimeter is used to measure the ignition time, mass loss, combustion products, and HRR, and the HRR represents the most important measurement. The 60–70% bioethanol fuel exhibited a flash point volatility of 16.6°C and flame temperature of 363°C (Babrauskas, 2002). On a cone calorimeter, the flash point requires a pilot ignition source with a temperature of 450°C. Figure 1 shows the experimental setup for HRR data retrieval.

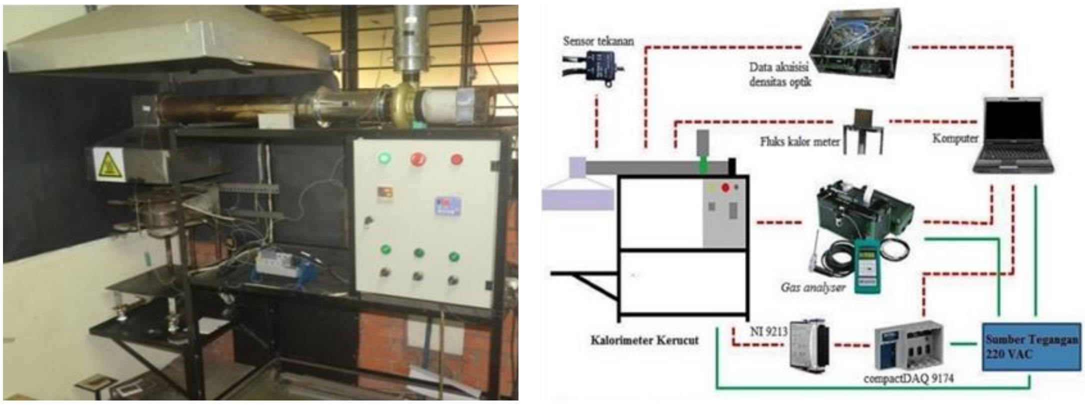

Figure 1 Experimental setup of the cone calorimeter

Cone calorimetry is a analyze HRR, elements contained in the smoke gas, and evaluate the mass differences in the bioethanol fuel. This experimental device meets the American Society for Testing and Materials (ASTM) standard (ISO 5660-1) in terms of the fire reaction test.

The components contained in the equipment were as follows:

1. Conical heater: The air heater was a truncated conical heater used in the calorimeter with a fire power of 4,000W/220V and a maximum temperature of 600°C. The heater temperature was set by the temperature control (PID) proportional integral derivative. The type of temperature controller used was a digital Autonics TZ4ST-14R.
2. Type-K thermocouple: This tool was used to measure the temperature in the samples tested reactors.
3. Electronic scale: This tool serves to measure the sample mass loss during the combustion process.
4. Channel ducting (exhaust): This component serves as the media regulator disposal of exhaust gases produced by the sample during the experiment;
5. Sample holder: This tool serves to hold the test sample during the experiment.
6. Data collection devices: The data acquisition devices used were the ADAM 4250 and 4018 which served to record the data from the heater thermocouple sensor, sample, and ducting.
7. Gas sampling line: The gas sampling line was connected to the Quintox-KM 9106 gas analyzer.

The testing process comprised fire safety equipment preparation, setting the test tool, and preparation for sample test. Before testing, it was necessary to prepare tools to support the testing process, namely heat-resistant gloves, a fire extinguisher, a data cable as the one-point apparatus, an exhaust fan in the testing environment, and protective glasses. It’s very important that the cable is not in contact with the cone calorimeter. Moreover, it was necessary to prepare the test equipment and ensure that all components fit tightly together in the specified position; these components were the cone calorimeter, exhaust blower, and gas analyzer. It was also important to ensure that the load cell was in good condition and ready for use and to ensure that the DAQ program was calibrated for use. The igniter needed to be ready to use, and the lighters had to be positioned within 1 cm above the fuel sample. The parameter in the experiment is: the heater has reached the temperature of 600°C, distance between the cups of bioethanol fuel and the heater is 5 cm, head radiation are vertical from the cups, and the gas analyzer was employed to measure oxygen levels and gaseous products of bioethanol combustion.

The temperatures of the flame, smoke, and orifice were measured for each of the samples. The rate of heat output is the released calorific value per unit of time in one sample of fuel as a result the exothermic reaction after the final application of energy. The HRR can be measured using a cone calorimeter. Data retrieval with a gas analyzer was also carried out to evaluate the levels of oxygen contained in exhaust gas. With the data concerning oxygen and the combustion gas outlet temperature, the value of the HRR could be calculated after determining the heat produced from burning. Hugget (2004) concluded that when they born perfectly, producing dry air and carbon dioxide, the heat production rate of liquid fuel and gas can be calculated using the following equation.

$$q = (13{,}1\ x\ 10^3).1{,}10\ .C\ \sqrt{\frac{\Delta P}{Te}}\ \frac{(XO_2^{\circ} - XO_2)}{(1{,}105 - 1{,}5XO_2\ )} \tag{2}$$

where q is the HRR (kW), C is a calibration constant for O_2 consumption analysis (m ^{½} Kg^{½} K^{½}), ΔP is the pressure drop across the orifice plate (Pa), Te is a gas temperature of the orifice plate (K), and XO_2 is measured mole fraction of O_2 in exhaust air. This equation can be used in the calculation of the rate of heat production of bioethanol fuel on an experimental basis using a cone calorimeter.

3. RESULTS

In the experiment, bioethanol passed through the cone calorimeter, sample and the combustion chamber in a vertical position was exposed to a cone of flux that emitted heat radiation to the sample, causing pyrolysis of bioethanol fuel. This ignited a fire that piloted ignition at 350°C. This suggested that combustion occurs spontaneously in a normal atmospheric with an ignition source at 350°C; this temperature is required to supply the activation energy needed for combustion. In the combustion process that occurs, the diffusion may be nearly stoichiometries, and the heat released by the fire in the mixing area of fuel and O_2 generates a fire takes place, as shown in Figure 2.

Testing was carried out to measure of the temperature data bioethanol flame using a type-K thermocouple; the measurement was fixed at the stove igniter in the cone calorimeter, and the fuel used was low-level bioethanol of 60–70% of each 100-ml sample. The distance between the fuel samples to the cone heater was 100 mm, while the fuel cup diameter was 50 mm. The combustion technique used pilot ignition at a temperature of 350°C. The experimental combustion HRR in cone calorimeter diffusion emerged when the bioethanol fuel and oxidizer air (O_2) mixed naturally in the combustion chamber of the cone calorimeter to generate a pilot ignition flame.

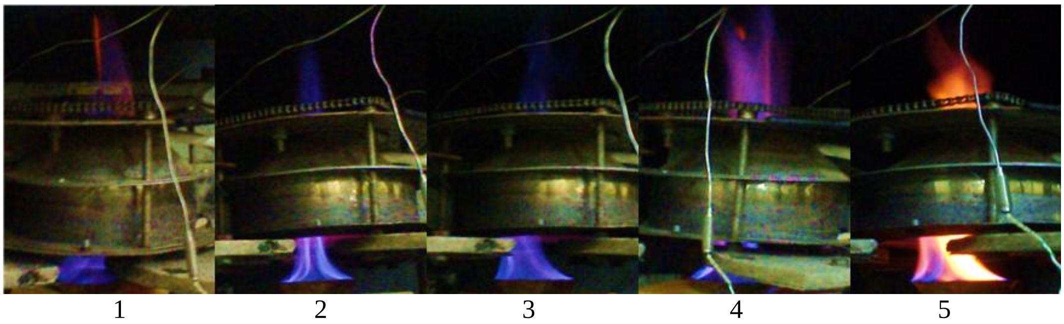

Figure 2 Experimental characteristics of the bioethanol heat release rate (HRR) in the cone calorimeter

In Figure 2, flame 1 shows the initial combustion, in which a flame arises with a reddish yellow tip; this indicates that the reaction process has occurred in the reaction zone of bioethanol fuel and air (O_2). The combustion reaction, this occurs rapidly at a constant pressure, and the reactant is passed into the reaction zone with the incomplete combustion products. The flame labeled 2 in the figure is approaching stoichiometric combustion, in which fuel and air (O_2) are mixed in the reaction zone due to the diffusion of molecules through forced convection, which mixes perfectly to produce a flame diffusion turbulent. Here the flames do not spread toward the fuel material due to a lack of oxygen into the air (O_2), as there will be a shortage of fuel. This flame is combustion in the area zone with a turbulent flame speed equal to that of the reactants in the combustion chamber, which obtain their energy from the movement itself to release heat. Flame 3 indicates complete stoichiometric combustion in which the fuel and air (O_2) mix in the combustion chamber to create stable flame diffusion turbulence. Stable rate of fire can be seen from the difference in the color of fire. The blue flame indicates the temperature difference between the higher and lower energy. The combustion in this case is more complete because the faster diffusion results in an increasingly blue color, as there is little or no soot. The images of the fire show the diffusion cone with high temperature, where the fire propagation speed equal to the speed of the reactants and the combustion products' velocity at release; this is due to changes in the density of the gas flowing perpendicular to the top surface of the cone diffusion flame as it forms. It is also influenced by the fluid nature of bioethanol fuel, which tends to flow because the density of the gas is lower than. In flame 4, visible changes appear from blue to red; this is due to incomplete combustion; a temperature drop occurs because the heat generated by the reaction is low. Thus, the temperature decreases in the reaction zone, and the combustion reactions that take place are not complete. The difference in concentrations of the reactants will trigger a diffuse flame with a poor mixture from the reaction zone, resulting in a product temperature decrease because the heat-production rate is lost to the environment. In the final stage of burning, flame 5 shows that the conditions that arise are is strongly influenced by the thermal conductivity and reaction speed; greater thermal conductivity of the fuel will result in a thicker flame with a slower reaction speed and lower power density. This can be seen in the change from a peacock blue flame to a yellow color, representing incomplete combustion. This occurs because the flame speed is much higher than the reaction speed of the fuel, the thermal H_2 diffusivity is greater than the C_2H_5OH fuel diffusivity, the mass of H_2 is greater than that of C_2H_5OH, and the kinetics of the reaction of H_2 are extremely fast because of the stages of the reaction $CO \rightarrow CO_2$, the soot products are the main factors that make up the color of yellow flame. Thus, the flame temperature in the reaction zone will release the products of combustion the smoke. The heat produced by the reaction is low. The temperature decreases in the reaction zone, and the combustion reaction cannot take place with a perfect result; thus, the flame will die.

4. DISCUSSION

Once the data were obtained, the next step was processing the data to determine the effect of burning on the bioethanol concentration for each test parameter. Temperature measurement was carried out for a bioethanol concentration of 60–70% with a sample size of 100 ml in an upright position in a heat radiation heater; a thermocouple was attached to a fixed location in the cone calorimeter to measure the flame. The observations showed that the flames' movement was influenced by the environment, as well as propagation of heat in the flame itself. The authors, found that the flame temperature value fluctuated sharply, and it was sometimes far from the average value of the temperature of the flame in other data. Moreover, the temperature of the smoke exhibited variations in value at different concentrations, and this also fluctuated over time due to a less stable flame.

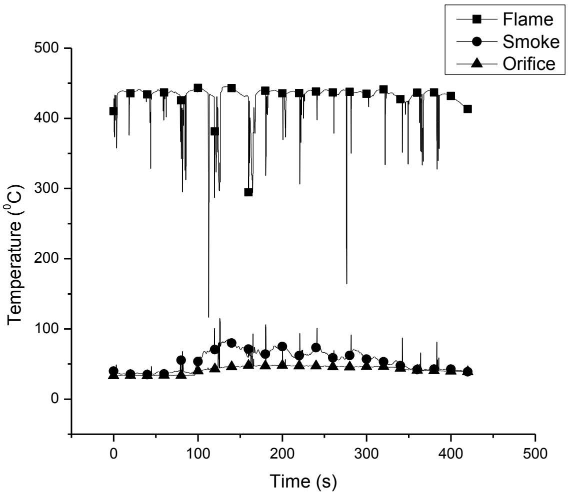

Figure 3 Smoke temperature, gas at the orifice, and flame in the combustion of bioethanol with a concentration of 60%

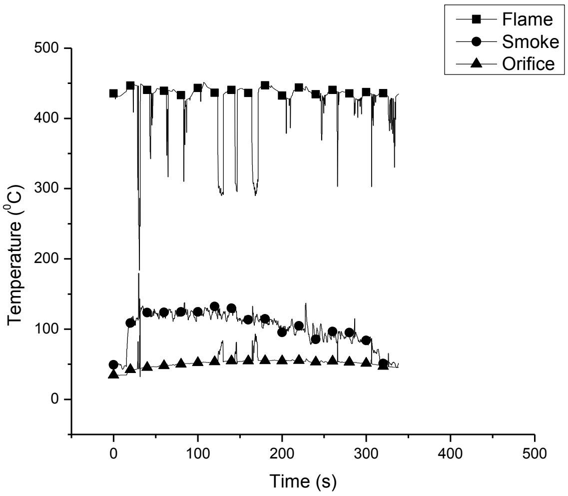

Figure 4 Smoke temperature, gas at the orifice, and the flame in the combustion of bioethanol with a concentration of 70%

The temperature measurement of a concentration level of 60% can be seen in the graph in Figure 3. It appears that for the flame, the maximum temperature was about 440°C, while it was

150°C for smoke and 80°C in the orifice. The value fluctuated due to the flame's unstable tendency. As previously described, the thermocouple was attached to a fixed constraint in the cone calorimeter to measure the flame. However, the flame's tendency is to move, and it is influenced by the environment and the propagation of heat in the flame itself.

The temperature of the smoke itself showed variations in value at different concentrations and fluctuated over time due to the unstable flame. This occurred because the air flow rate reacting with the fuel diffusion flame of cannot be controlled in an air atmosphere. The combustion chamber in the cone calorimeter was open resulting in significant differences in the flame, smoke, and orifice temperatures. Figure 4 shows that the temperature difference for the smoke and orifice was not significant while the combustion process was ongoing for a duration of 400 s. The graph indicates that the temperature flame instability decreased to a temperature of 110°C at 110 s and 150°C at 270 s; this was due to the low levels of bioethanol in the fuel, at 60%, which mean that 40% of the fuel still contains water. This also occurred because the elements of fuel do not burn completely and the combustion process occurs independently.

The temperature measurement of a concentration level of 70% can be seen in the graph in Figure 4. It appears that the maximum flame temperature had a value of about 450°C, while those of smoke and the orifice were 180°C and 100°C, respectively. The value fluctuated due to the flame's unstable tendency. As previously described, the thermocouple was attached to a fixed constraint in the cone calorimeter to measure the flame. However, the flame's tendency is to move, and this is influenced by the environment, as well as the propagation of heat in the flame itself. Therefore, the most value for the temperature of the flame fluctuated sharply, and they were sometimes extremely far from the average value of the temperature of the flame in other data. The flame temperature tended to fluctuate at an average of 300°C, and an extreme temperature of 170°C was observed at the start of combustion at 40 s. The smoke temperature was 130°C, while that of the orifice was 80°C. The 70% concentration of bioethanol fuel showed better performance, but a red flame was still visible, and the temperature fluctuated over time because the fuel still contained 30% water. This also occurred because not all elements of the fuel burned completely and the combustion process occurs independently.

The HRR is an important parameter to characterize flame based fuels; in this study 60% and 70% bioethanol fuels were used. A tendency appeared for the flame temperature to be higher in the 70% fuel than in the 60% fuel, content of bioethanol fuel that will produce a high-more complete combustion. In the observations, a change in color of the flame from red to yellow to blue appeared. This was caused by higher fuel combustion processes and a faster burning time because of the volatile nature of fuel, which released smoke temperature to speed up the process in air, oxidization speed reaction with atmospheric oxygen resulted in a faster HRR

Figures 5 and 6 show that the trend of flame temperatures is higher with greater concentrations of bioethanol. However, further analysis using a cone calorimeter for measuring the HRR of 60–70% bioethanol is necessary to determine the strength of the relationship between the two variables. A high concentration of bioethanol for combustion greatly affects the HRR, where there is a tendency toward a flame temperature is higher; this results in a greater HRR because more fuel is burned. However, this study also was heavily influenced by the volatile nature of fuel for combustion in the external combustion chamber atmosphere. This greatly affected the combustion process.

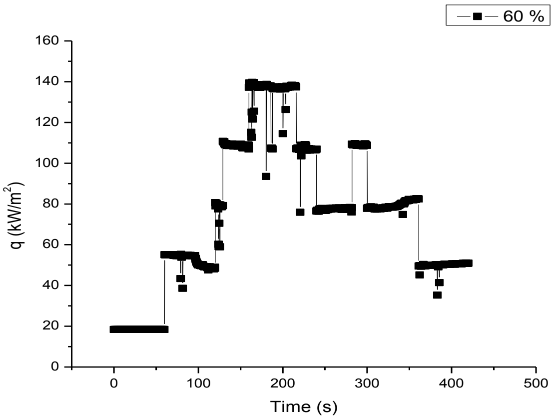

Figure 5 Heat release rate (HRR) of bioethanol with a concentration of 60% versus time

The graph shown in Figure 5 illustrates the HRR of bioethanol with a concentration of 60% with time; the initial HRR was 20 kW/m^2, while the final HRR at 450 was 55 kW/m^2, the length of time of 450 s. Based on the observations, it can be stated that the speed of the fire greatly affects the HRR. Based on the experiment, the HRR of 60% bioethanol was affected by the cross-sectional area of the combustion chamber, and the volumetric flow rate of air and fuel mixture diffusion burn with an optimum burning time of 200 s at a rate of heat release of 140 kW/m^2.

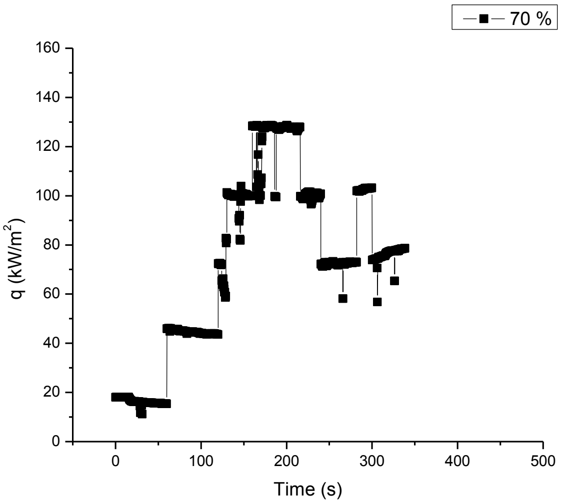

Figure 6 Heat release rate (HRR) of bioethanol with a concentration of 70% versus time

The graph shown in Figure 6 illustrates that a higher concentration of bioethanol in the fuel caused it to burn more quickly because of the higher combustion reaction rate. This was partly caused by the high concentration; bioethanol will evaporate reacts much faster to the air (higher volatility level), so that bioethanol will be more easily diffused in the air. As a result, the combustion will be more rapid because the fuel and oxidizer are mixed better. The HRR of 70% biethanol burnt in the cone calorimeter was determined based on the experimental results for the mass release rate, oxygen consumption, and heat loss of with an energy balance analysis. The products of combustion exhaust gas were measured at 20–140 Kw/m^2, with an optimal tine of 200 s. The overall time was 350 s, showing that the fuels burn faster due to its volatile nature; the fuel quickly evaporated into the surrounding air, so some of it was not burned. This was influenced by the experimental model, in which external combustion was conducted.

5. CONCLUSION

At higher concentrations of bioethanol than 60% and 70%, the HRR will be greater; this will result in a higher value of the energy content per unit mass for higher concentrations. Moreover, the mass reaction rate will be increased at higher ethanol concentrations. There is the possibility of a correlation between the levels of bioethanol and flame temperature; at higher concentrations, the temperature of the flame is also likely to be higher. However, of the test samples, it appeared that the 60% bioethanol sample had the highest HRR. Flame combustion of bioethanol can be produced in a temperature range of 445–463°C with a longer burning time of 450 s, but the flame temperature is low and flame color is yellow-reddish, moving toward blue. It can be concluded that low-level bioethanol of 60% and 70% concentrations can be used as fuel in the combustion chamber of a cone calorimeter. The heavy mass of the fuel that comes out is equal to the mass of fuel burned due to the activation energy obtained from the combustion reaction of bioethanol to increase the temperature of the fuel in the combustion chamber.

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