JBAT 7(1) (2018) XX – XX

p-ISSN 2303 0623
e-ISSN 2407 2370

Jurnal Bahan Alam Terbarukan

Terakreditasi: SK No.: 36b/E/KPT/2016
http://journal .unnes.ac.id/nju/index.php/jbat

Effect of Pressure in Organic Waste Burning Process on the Combustion Rate

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DOI 10.15294/jbat.v7i1.XXXX

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Article Info

Article history:
Received
October 2017
Accepted
December 2017
Published
June 2018

Keywords :
combustion rate;
organic waste;
scrubber;
pressure

Abstract

The combustion process of organic waste has several drawback which produce flue gases containing pollutants SO_2, HCl, tar and heavy metals (Cu, Hg, Fe, Zn, Pb, and Cr). The pollutants can be removed from the flue gas using a water scrubber. The process of absorption using the water scrubber can cause a rise in pressure in the combustion chamber.This research aims to study the effect of combustion process pressure of organic waste on the combustion rate. The research was conducted by burning waste in the reactor at various flow rate of combustion air. The exhaust gases of combustion then flowed into ihe water scrubber that the height varied. The change in pressure and combustion rate of each variation of the air flow rate and the height of the water scrubber was measured. According to the results, it was obtained the correlation of combustion pressure to the combustion rate was $y = 0{,}844e^{-0{,}2X}$, where y = the combustion rate (kg/min) and x = combustion pressure (gauge, mm H_2O). In addition, the increase in combustion pressure up to 21 mm of water, caused a reduction in combustion temperatures up to 50 ° C, while the combustion rate decreased to one-tenth from atmospheric combustion.

**This article is a revised and extended version which had been presented at SNTK UNNES 2017, Semarang, Indonesia, September 20th, 2017.*

INTRODUCTION

In Malang city, organic waste is the biggest component of city waste which is equal to 68% (BPS, Malang city, 2013). According to Ruug (1997) the definition of organic waste is biodegradable waste. So far, the utilization of organic waste is as compost and most of it is still disposed of in landfills (TPA) that can produce methane gas for fuel. However, this process takes a long time (McDougall et al., 2001). Its impact on the long term is that it requires additional land disposal (Julianus & Hermana, 2009).

One of the relatively quick processing alternatives with a residence time of about 73 minutes is by burning (Naryono, et al., 2016). Burning organic waste produces pollutants in the combustion exhaust gases that must be removed before being discharged into the outside air. One of the effective methods for removing exhaust gases is by absorption using a bubble scrubber (Phuphuakrat et al., 2011). However, this scrubber system can reduce the rate of combustion, because the flue gas flow is inhibited by the hydrostatic pressure of the absorbent fluid in the scrubbing tank.

At the the designing and operation of the reactor, information on the correlation data between the combustion process pressure and the combustion rate should be known. It can thus be used as a basis for choosing the right system and mode of operation so that a high combustion rate system can be generated.

Some previous researchers have studied the correlation of pressure with combustion rate. According to Arena (2012) the pressure on the fluidization reactor can decrease the speed of the gasification process. Characteristics of pressure on gasification and combustion processes commonly

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ISSN 2303-0623
e-ISSN 2407-2370

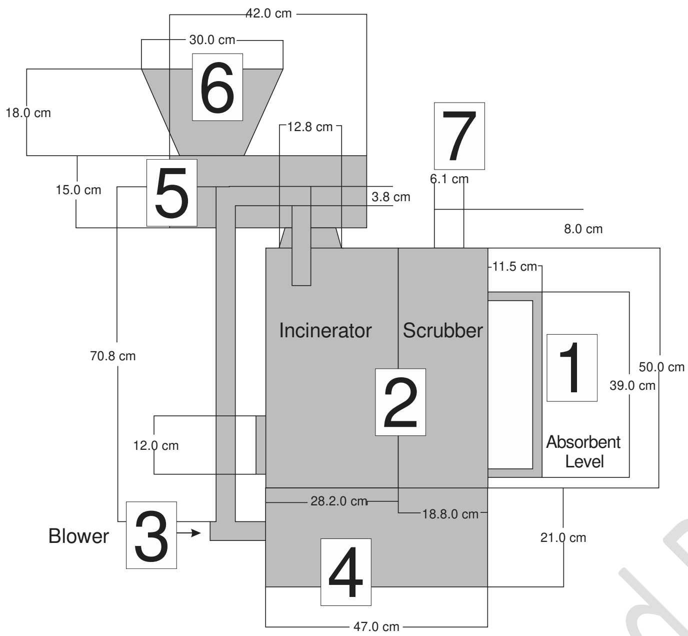

Figure 1. Scheme of research apparatus. 1. water manometer, 2. combustion chamber and scrubber, 3. blower, 4. ash dischage, 5.motor, 6.feeder, 7. flue gas pipe

used are atmospheric pressure. The pressure of a process greater than atmospheric pressure can lower the process temperature. Balas et al. (2012) examines the effect of gasification process pressure on heating value gas which indicates that the higher the heating value of the lower gas pressure. However, both studies did not address the specific stresses imposed on the scrubber process. Furthermore, the research did not use organic waste material.

Howard (1968) conducted a review of the effect of temperature variables, material size, combustion time and pressure on the process of burning refused waste (refuse). Nevertheless the explanation is still general, it is not specific to a particular process. This study aims to obtain a specific correlation between changes in pressure caused by the absorbent water level used in the scrubber process against the organic waste combustion rate. Water scrubber height variables studied were 10 cm, 15 cm, 20 cm and 25 cm. The results of this study can be used for basic design process and operation of organic waste combustion system equipped with scrubber. One example of its utilization is to determine how high the water scrubber can produce a permissible combustion rate and produce cleaner flue gas.

RESEARCH METHODOLOGY

Schematic apparatus for the study is shown on Figure 1. Initially prepared organic waste that have been dried as much as 2 kg. The waste was obtained from Tlogomas temporary landfill (TPS), Malang city. This waste is then partly taken samples for proximate analysis to determine the characteristics of waste water content, volatile and ash. The chemical elemental of waste (C, H, O) is calculated empirically using the equation published by Shen et al. (2010). Based on the calculation, chemical composition of organic waste studied was C = 42.78%, H = 5.07% and O = 35.45%. This waste is then placed on a wire basket container to make it easier when inserting and picking up waste inside the combustion chamber. The next step is to prepare the waste incineration equipment, then fill the water manometer tube (1) with varying heights according to the height of the variables studied. The waste in the basket is then put into the combustion chamber (2). Initial burning is done using charcoal, which is placed outside the waste basket so that the charcoal mass does not affect the waste mass. At the time the waste started to burn it was considered as time (t = 0). The combustion process is carried out at variations of air flow rate of 1.5 l/sec, 2l/sec, 2.25 l/sec and 2.51/sec by adjusting blower (3). Flue gases are flowed to scrubbers that have been filled with water of varying heights: 10 cm, 15 cm, 20 cm, and 25 cm. As the exhaust flows through the scrubber, there is a change of pressure inside the combustion chamber which is then measured using a water manometer. Each time interval of 15 minutes those are 15th, 30th, 45th, 60th and 75th minutes baskets removed from the combustion chamber and then weighed to determine the mass of waste after combustion. The next step was to calculate the combustion rate at various variables of flow rate and water scrubber heights. The waste combustion rate was calculated from the formulation of the mass difference before and after burning divided by the length of time of combustion.

RESULT AND DISCUSSION

The Effect of Scrubbing Liquid Height on the Combustion Pressure

The pressure on the combustion chamber is influenced by the high fluid scrubber used to absorb the flue gas. This is because to get out of the combustion chamber, the exhaust gases must pass through the scrubbing fluid. The flow rate of exhaust gas out of the combustion chamber was obstructed by the scrubbing liquid, causing the pressure inside the combustion chamber to increase. The effect was studied by making a combustion experiment on variations of air flow rate of 1.5 l/sec, 2 l/sec, 2.25 l/sec and 2.5 l/sec. The combustion gases are then flowed in a water scrubber which height was varied as 10 cm, 15 cm, 20 cm, and 25 cm before being discharged into atmosphere. Changes in pressure within the combustion chamber were then measured using a water manometer at each time interval of 15 minutes, 30 minutes, 45 minutes, 60 minutes and 75 minutes.

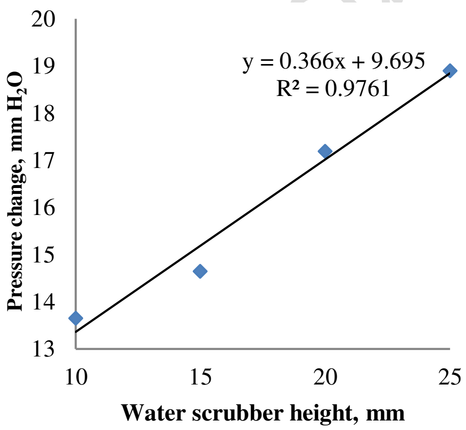

Figure 2. Pressure change at various water scrubber heights.

The fluctuations of the height change of the air manometer at the time of air flow with a variation in the flow rate of 1.5 to 2.5 l/sec at the same water scrubber level is not too high. Range of height change of water manometer for each water scrubber height 10cm, 15 cm, 20 cm, and 25 cm is 1-2mm. Range of water manometer height change at variation of flow rate 1.5 – 2.5 l / sec with variation of 0-25 cm water scrubber height is 0 - 21 mm. This condition indicates that the effect of the pressure change in the combustion chamber was the height of the water scrubber. Therefore, the reference parameter causing the change of pressure in the combustion chamber was the change in the water scrubber height.

The measurement results of these pressure changes vary depending on the height of the water scrubber. The measurement data of pressure change (in mm H_2O) ranged from 15 to 75 minutes, with an air flow rate of 1.5-2.5 l / sec at each scrubber water level of 10, 15, 20, and 25 cm, then calculated the mean value. The result of this calculation is then made high correlation curve of air scrubber vs. pressure changes, as shown in Figure 2.

Based on Figure 2, it shows that at various variations of the combustion air flow rate, the higher the water scrubber level the more pressure increases of the combustion process linearly with the equation of y = 0.366x + 9.695, where y = pressure changes (mm H_2O), and x = height water scrubber (mm). This is because the pressure drop of exhaust gas flowing in the water scrubber is increasingly proportional to the higher water scrubber.

The correlation can be explained using the flow friction equation in the pipe or the porous medium following equation 1 (Geankoplis, 1983). Based on this equation it can be seen that the correlation between pressure drop with height of water scrubber and linear fluid velocity. From the equation it can be shown that the higher water scrubber (ΔL) and the linear velocity of air (v) the greater pressure drop would be. This condition causes an increase in combustion chamber pressure.

$$\Delta P_f = 4 f \rho \frac{\Delta L}{D} \frac{v^2}{2} \qquad (1)$$

whence ΔP_f = pressure drop, ΔL = water scrubber height, v = linier velocity of fluid, f= friction and ρ = density of fluid.

Effect of Air Flow Rate to combustion rate at Atmospheric Pressure.

According to Yang et al. (2004) the combustion rate is proportional to the combustion

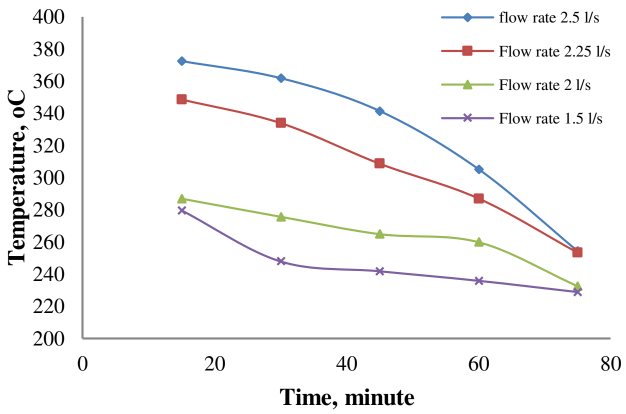

Figure 3. Atmospheric combustion temperatures at various combustion air flow rates.

air flow rate until it reaches a critical condition, then it will decrease if the air flow rate is greater than the critical condition. Likewise, Lee & Lin (2007) explain that there are two combustion areas, that are air deficiency and excess air. Deficiency air combustion is a combustion process that the ratio of fuel to air is lower than the requirements of stockiometric air. In contrast to combustion with excess air, the ratio of fuel to combustion air is higher than the stoichiometric requirement. Under stoichiometric conditions, it produces the highest combustion temperatures.

The results of this study indicate that combustion carried out at atmospheric pressure with a variation of 2.5 l/sec flow rate, 2.25 l/sec, 2 l/sec, and 1.5 l/sec, the combustion characteristics are the type of air deficiency combustion. This argument is based on a comparison of theoretical stochiometric temperature calculations of 411°C with the highest temperature of experimental combustion at air flow rate (2.5 l/min) which is only about 380°C. This condition indicates that the combustion process in this study the amount of air is smaller than the stoichiometric requirement or the type of air deficiency.

The efect of the combustion air flow rate against the atmospheric combustion temperature in this study is shown Figure 3. The higher the combustion flow rate, the higher combustion temperature in the 15-75 minute time range. This corresponds to the combustion characteristics of areas with air deficiency. In Figure 3 it can also be seen that in the range of time variables studied, combustion temperatures decreased in all variations of air flow rate. This is due to the longer burning time, the waste mass decreases so that the ratio of burned waste to the air decreases. Its combustion characteristics change from air deficiency combustion to excess air combustion. The impact is that most of the combustion heat is absorbed by the excess air so that the combustion temperature decreases.

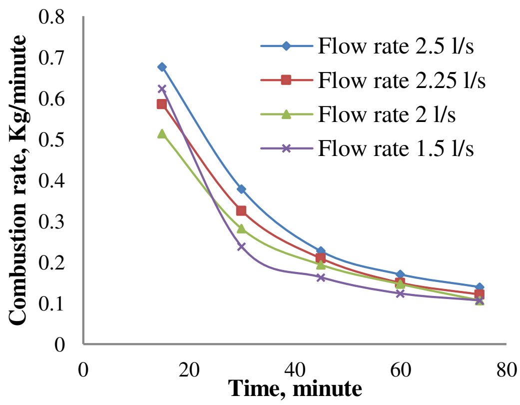

Figure 4. Atmospheric combustion rate in various combustion air flowrate.

Neves et al. (2011) provides an empirical correlation that can be used to predict the effect of combustion temperatures on unburned residual coal. Based on the result of simulation using Neves equation, can be obtained correlation between combustion temperature to unburnt coal. The simulation results show that at the same combustion time interval, the higher the temperature the remaining unburned char be smaller. The same condition also occurs when organic waste is burned ie the higher the burning temperature during certain time interval, the smaller of the remaining unburned waste. By referring to the calculation formula of combustion rate can be correlated that the higher the combustion temperature, the combustion rate is also higher. The atmospheric combustion rate of

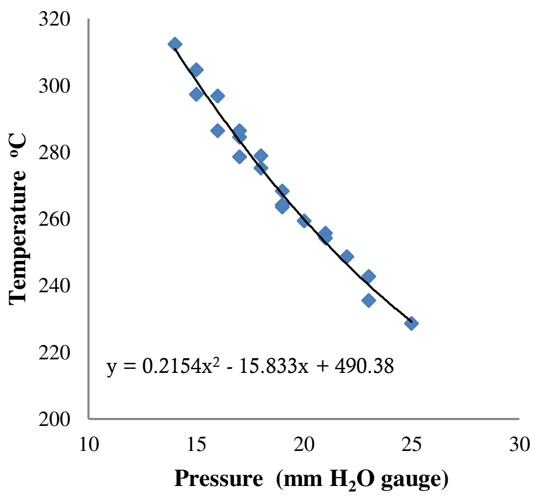

Figure 5. Temperature of combustion at various pressures

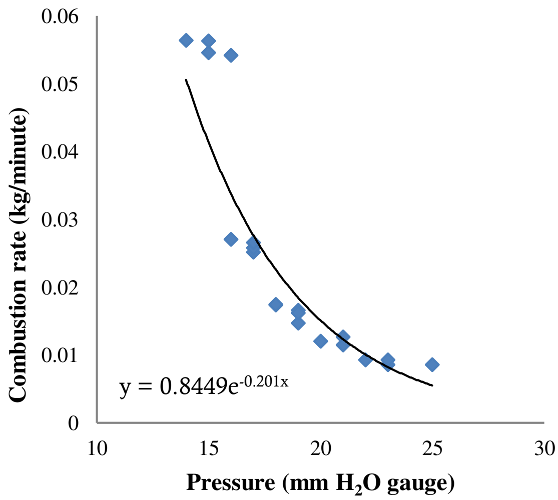

Figure 6. Combustion rate at various pressure

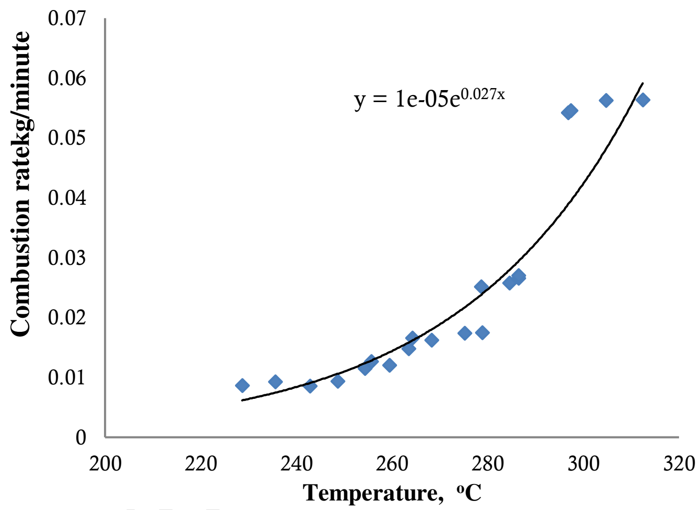

Figure 7. Pressurized combustion rate at various temperature.

waste during the 15-75 minute interval, at various variations of the combustion air velocity observed is shown Figure 4.

The effect of pressure on combustion rate

Changes in pressure inside the combustion chamber affect the combustion rate. This influence has been studied by Balas et al. (2012), and Chunhy et al. (2010) on the gasification process. The results showed that the higher the pressure, the lower the gas heating value so that the combustion process temperature is lower. Another researcher, Howard (1968) presented that the higher pressures the lower the combustion rate.

As discussed in sub chapter The Effect of Scrubbing Liquid Height on the Combustion Pressure, the pressure changes in the combustion chamber are influenced by the high water scrubber. By passing the combustion gas into the water scrubber, it causes an increase in pressure in the combustion chamber. This is due to the flow of exhaust gas inhibited water scrubber when it will come out of the combustion chamber. The impact of the amount of combustion air in the combustion chamber is greater than the amount of atmospheric combustion air. Increasing the amount of combustion air causes the combustion temperature to decrease, because the combustion heat is absorbed by air at larger amounts. The characteristics of combustion combustion include the type of combustion that excess air is the greater the excess air from the needs stokiometris the lower the temperature.

The effect of pressure (in mm H_2O gauge) on the combustion temperature of the results of the study is presented in Figure 5 which shows that the higher the pressure, the lower the combustion temperature. With the lower burning temperatures, the remaining mass of unburned waste is getting bigger. The impact of combustion rate was lower. Based on Figure 5, it shows that the combustion temperature is inversely proportional to the pressure. The greater the pressure, the lower temperature would be. The correlation of the combustion temperature and pressure follows the two-polynomial equation with the equation $y = 0.215x^2-15,83x + 490.3$ where y = the temperature ^oC and x = pressure in mm H_2O gauge.

The effect of pressure on combustion rate of the research results is shown in Figure 6. As well as the effect of pressure on temperature, the pressure effect on combustion rate is also inversely proportional. The higher the pressure, the lower the combustion rate. following the exponential equation $y = 0.844e^{-0.20\,x}$ where y = the combustion rate and x = pressure in mm H_2O gauge.

Figure 7 shows the relationship between pressurized combustion temperature and combustion rate following exponential equation $y = 10^{-5}e^{\ 0.027x}$ where y = combustion rate, and x = combustion temperature. This equation can be used simultaneously with the correlation equations of pressure and combustion temperature to correlate the pressure, temperature and combustion rate. The three relationships can be searched by inputting the desired pressure value on the pressure correlation equation and the combustion temperature. The combustion temperature of the calculation results is then incorporated into the correlation equations of combustion temperature and combustion rate, or used Figure 7 directly.

The use of bubble-type scrubbers in addition to having advantages with simple construction, also has a weakness that has a relatively high pressure drop, depending on the height of the water scrubber. The higher water scrubber, the more optimal the process of absorption of pollutants in the combustion flue gas would be. However, with the higher water scrubber, the combustion pressure gets higher. This condition causes a decrease in combustion temperature which affects the decrease of burning speed.

The temperature decrease of the bubble-type scrubber combustion in an organic waste combustion system can reach 50ºC. Likewise, the combustion velocity drops to a tenth of atmospheric burning speed. In the design of combustion systems, this condition needs to be anticipated e.g by adding a vacuum system that can regulate the speed of air circulation of combustion, so as not to accumulate in the combustion chamber. The vacuum system is connected to the exhaust gas exit space after passing through the scrubber. This system works to suck the exhaust gases so as to reduce the accumulation of combustion air in the combustion chamber. The accumulation of air in the combustion chamber can cause excess combustion air so that the temperature of the combustion chamber decreases as part of the combustion heat is absorbed by excess air.

CONCLUSION

In this research we have studied the characteristic of combustion velocity at higher pressure than 1 atmosphere caused by inhibition of flue gas flow in bubble type scrubber. The change of combustion pressure was more dominantly affected by the high fluid scrubber than the combustion air flow rate. Based on this research can be concluded as follows:

In the atmospheric combustion process the greater the combustion air flow rate, the higher the temperature and the combustion rate. In the variation of the combustion air flow rate of 1.5-2.5 l / s, the combustion rate increases in the range of 0.14 kg/min to 0.7 kg/min. The higher of the water level in the scrubber, the higher the combustion pressure would be. In variations in the water level of scrubber 10 to 25 cm, the combustion process pressure increases fluctuated in the range of 13-21 mm water. Increasing the height of the water scrubber caused a decrease in the rate of burning. Changes in combustion process pressures was up to 21 mm water, caused a reduction in combustion temperatures up to 50ºC, while the combustion rate dropped to a tenth of the time from atmospheric combustion.

ACKNOWLEDGMENTS

The authors thanks the State Polytechnic of Malang which is funding this research with DIPA fund, SP DIPA No : 042.04.2.401004/2016

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