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High density Polyethylene plastic waste treatment with microwave heating pyrolysis method using coconut-shell activated carbon to produce alternative fuels

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Abstract. Pyrolysis is a technology that could crack polymer such as plastic waste into alternative fuels. This research uses microwave heating method, which more efficient than conventional heating method. The plastic waste used is 200 grams of HDPE, with feed to catalyst weight ratio are 1:1, 0.6:1, 0.4:1. Pyrolysis was run at temperatures of 250, 300, 350, & 400 °C for 15, 30 and 45 min. From the experimental result, the best variable of pyrolysis process with microwave method is at 45 minutes, at 400°C, and 1:1 feed to catalyst weight ratio. Result shows that yield of liquid and gas product is 99.22%; yield of residue is 0.78%; value of liquid product's composition (cycloparaffin and n-paraffin) is 54.09% and concentration of methane gas is 10.2%.

1. Introduction

Pyrolysis is one of the effective ways to process plastic waste, it can crack polymer such as HDPE plastic by just using heat energy [1]. Generally, there is two methods of pyrolysis that is conventional heating and microwave heating method. For conventional heating method, heating process is carried out in the container by conduction while in microwave heating method heating process is carried out directly on the material. By heating directly on the material pyrolysis process occurs less time and energy. So, it can be concluded that microwave heating method more effective and efficient than conventional heating method [2]. In the pyrolysis process occurs polymer scissions. For polyethylene pyrolysis occurs *random scission* that a lot kind of scissions happen but dominated by *beta scission* which produces olefins group of hydrocarbons. Heat will continue to cut the bond of carbon groups so that will form simpler range of hydrocarbon groups [1]. For microwave heating method pyrolysis needs a catalyst as a thermal assist and a cracking catalyst. For thermal assist function, catalyst must contain organic compound so it can absorb microwave and convert it into heat and for cracking catalyst function it must contain Al and Si compound so it can reduce activation energy of cracking reaction [3]. However, most of catalyst used for pyrolysis have a high price. In the other hand CSAC (Coconut Shell Activated Carbon) that known as a catalyst which made from a waste material with a low price have a potential as catalyst for pyrolysis. Because CSAC have enough Al and Si contained and basically CSAC is an organic compound [4].

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2. Materials And Methods

2.1 High Density Polyethylene (HDPE)

HDPE plastic used in this research was a transparent HDPE plastic bottle which usually used for chemicals and drugs container. The bottle chopped manually into small section of $1 \times 1 \text{ cm}^2$. HDPE was a thermoplastic material which formed from carbon and hydrogen compound [5]. Density of HDPE was about $0,964 \text{ g/cm}^3$ [6].

2.2 Coconut Shell Activated Carbon (CSAC)

Catalyst that used in pyrolysis process usually a zeolite that contained a lot of Si and Al compound but it's expensive [7]. Coconut shell waste had a potential to be used as pyrolysis catalyst because it contains a lot of C, Al, and Si [8]. Research used a local commercial CSAC which then reactivated by burned in a furnace for two hours at 700°C . CSAC that used had $334.771 \text{ m}^2/\text{g}$ of surface area and contained 5.08 % of Si, 1.49 % of Al and 68% of C. Material that used as a catalyst must have a surface area about $300\text{--}1000 \text{ m}^2/\text{g}$ [9]. Could be conclude that CSAC used in this research were qualified as a pyrolysis catalyst

2.3 Microwave pyrolysis instrument construction

This research used instrumentation such as reactor, microwave, connectors, thermocouple, condenser and vacuum pump. The microwave used was a domestic microwave which was perforated with two holes on the top so the connectors could pass trough of it. The reactor used is 500 ml two-neck flask which then assembled with glass connector, condenser, liquid product container that shaped like Erlenmeyer that connected to vacuum pump and then constructed as the construction in the figure 1.

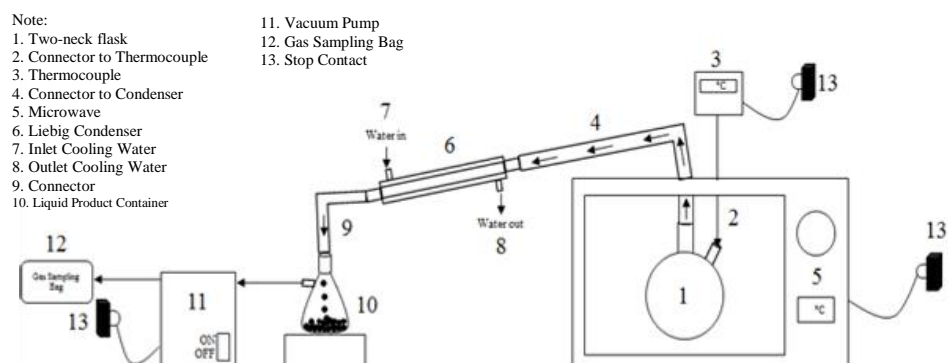


Figure 1. Pyrolysis instrumentation construction .

2.4 Pyrolysis Procedure

After all instrument and materials were set-up, vacuum pump and cooling water circulation turned on. Then the microwave turned on and keep on raising the set of microwave power until reach the temperature variable that was 250°C , 300°C , 350°C , and 400°C . at the moment that system reach the temperature that maintained the temperature by set down or up the microwave power specified time variable which was 15 minutes, 30 minutes, and 45 minutes.

After the pyrolysis process was completed the liquid product and the residue collected, then weighted it to get the yield of the process. To get the compositions of the product took a sample of liquid and gas product to be analyzed later.

2.5 Product Composition Analysis

To analyzed liquid composition of liquid product used GC-MS (*Gas Chromatography – Mass Spectrometry HP 6890 GC Method: Liquid 16 M*) analysis. Liquid product would be analyzed thoroughly and quantitatively. The gas product would only be analyzed methane content quantitatively used GC (*Gas Chromatography Agilent Hewliet Packard 6890 Series*). Because methane was the simplest compound for the result of hydrocarbon cracking process and methane was one of the alternative fuel that abundant [10].

3. Result And Discussion

3.1 Principle

Result's quality of pyrolysis could be seen from the product yield and the composition. Liquid product contains a lot of components that would be divided into 5 groups of hydrocarbons which were n-paraffin, cycloparaffin, olefin, alkynes, and aromatics. For alternative fuels liquid must contained a lot of cycloparaffin and n-paraffin and prohibited to contain too much olefin, alkyne and aromatic groups. So, more quantity of n-paraffin and cycloparaffin showed a better quality of liquid product produced. For gas product, amount of methane would represent amount of other desired gas product such as ethane, propane, butane, etc. Because methane was the simplest result for pyrolysis and the most difficult result to form. So, more amount of methane compositions showed a better quality of gas product.

3.2 Effect of Operation Time on Results

In the research to determine the effect of the operation time, the temperature and number of catalysts were determined at 300°C and 1:0,6 feed to catalyst weight ratio. Operation time would affect both yield and the composition of product. After the result were obtained the best time would be used as a fixed variable in the next run of the research for determined effect of others variable.

3.2.1 Effect of Operation Time on Yield of the Product, The result of the research for determined effect of operation time could be seen on figure 2. From figure 2 could be observed that at 15 minute of operation time liquid product produced just 8.16 gram/gram feed and continue increasing with the increase of operation time used, and reach 46.9 gram/gram feed at 45 minute of operation time. Residue kept decreasing with increasing of operation time from 50.51 gram/gram feed at 15 minutes to 9.36 gram/gram feed. It happened because of more time operation that used more energy that given to plastic to crack into simpler compound. [1]. But, a different thing happened to gas product that given a fluctuate pattern. At 15 minute of operation time yield gas product reach 41.69 gram/gram feed and increased at 30 minute of operation time into 65.67 gram/ gram feed then decreased at 45 minute of operation time into 43.74 gram/ gram feed. Indicated during a short operation time pyrolysis tend to produce a lot of gas that easy to be produced such as CO₂, CO, etc. With the increase of operation time pyrolysis get more energy to start crack the plastic to heavy fraction which was a liquid product.

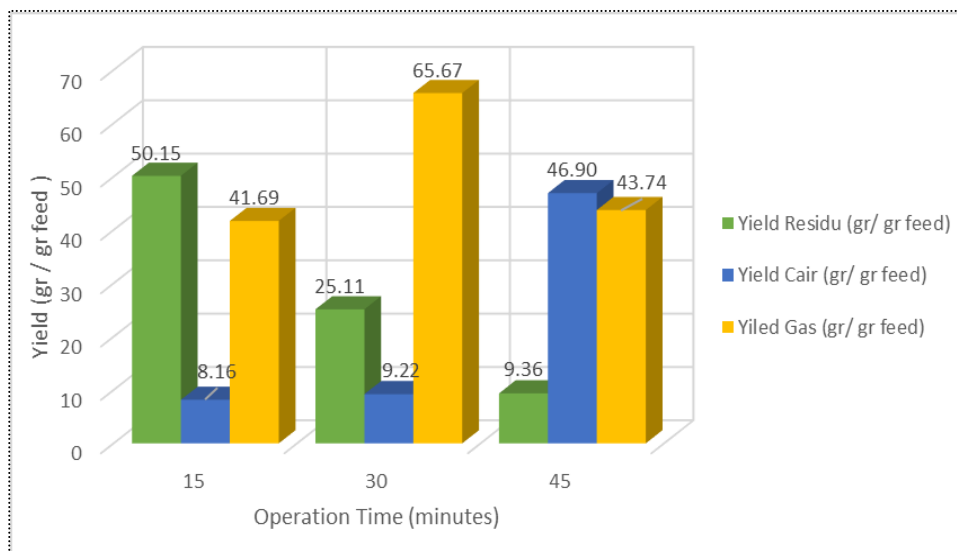


Figure 2. Effect of operation time on yield of the product.

3.2.2 Effect of Operation Time on Composition of the Product, From figure 3, could be seen that the composition of liquid product at 15 minute of time operation only legible of 13.7% of n-paraffin. It happened because the low quality of product which cause a poor analysis of GC-MS. Quality of product was indicated from the physical appearance which was higher the quality, the color getting closer to yellow and being more dilute. Product from 15 minutes time operation shows dark green color and very viscous liquid. The liquid product from 30 minutes of operation time had a lot better quality and thus affect the analysis of GC-MS. Total amount of n-paraffin and cycloparaffin was 40.84% at 30 minutes and continued increase into 41.38 % at 45 minute of operation time. So, could be conclude that the longer the operation time better the result obtained.

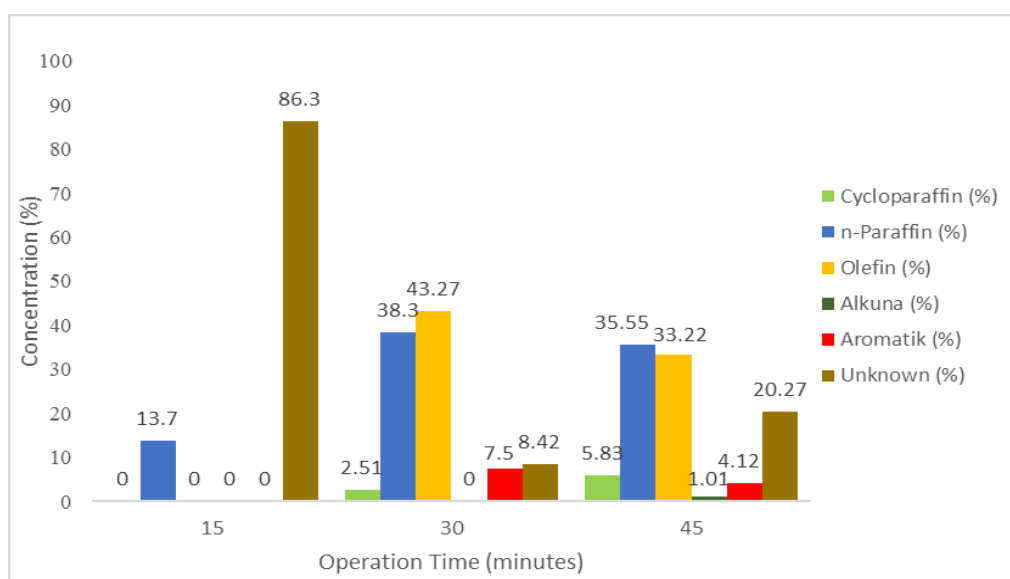


Figure 3. Effect of operation time on composition of the liquid product.

For the result of the composition of the gas could be seen in figure 4 which showed that the methane content continues to increase with the increase of the operating time used. The composition of methane increases from 2.4 % at 15 minutes of operation time into 7.1 % at 45 minutes of operation time.

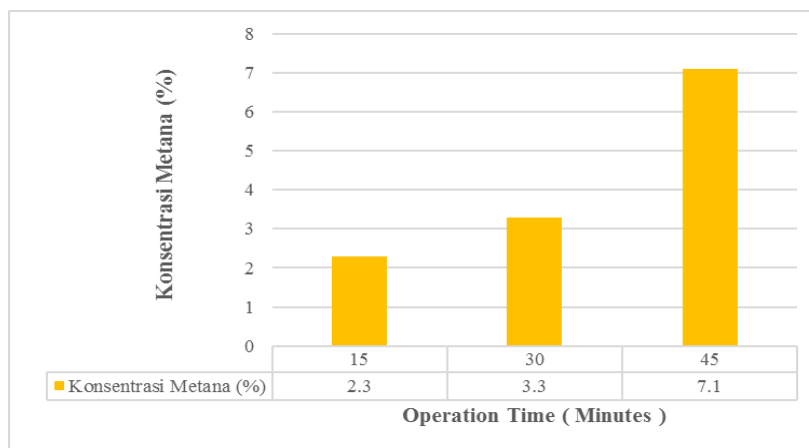


Figure 4. Effect of operation time on methane concentration.

3.3 Effect of Temperature on Results

In the research to determine the effect of the temperature, the operation time and number of catalysts were determined at 45 minutes and 1:0,6 feed to catalyst ratio temperature would affect both yield and the composition of product. After the result are obtained the best temperature variable would be used as a fixed variable in the next run of the research for determined effect of others variable.

3.3.1 Effect of Temperature on Yield of the Product, Figure 5 shows the yield change in each temperature variable. Yield of liquid product continue increasing from 9.43 gram/ gram feed at 250°C into 52.24 gram/ gram feed at 350°C but decreasing to 47.59 gram/ gram feed at 400°C while the yield of gas initially decreased and start to increase at 300°C. It can happen because higher temperature that used, more energy given to pyrolysis process and cause more liquid product produced, but at a certain point the energy will excess and thus make the product that initially a heavy fraction of hydrocarbon (liquid product) being re-crack into a lighter fraction of hydrocarbon (gas product) [1].

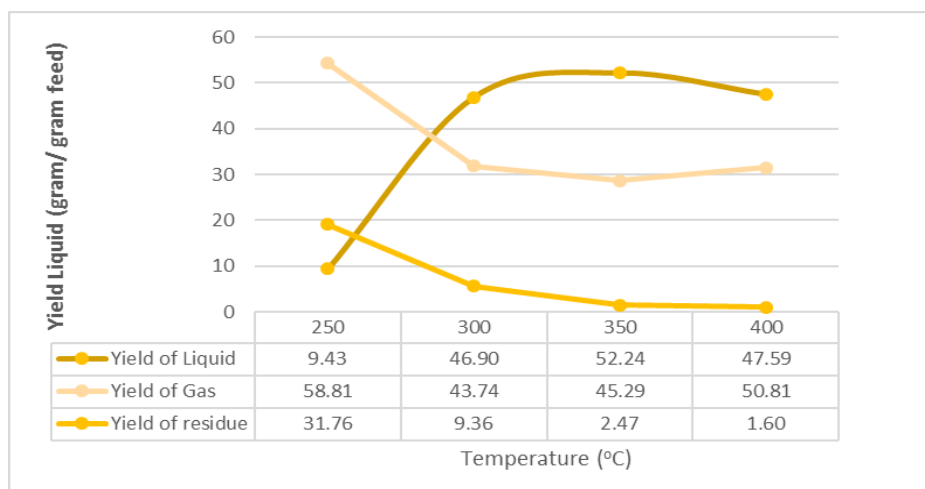


Figure 5. Effect of Temperature on yield of the products.

3.3.2 Effect of Temperature on Composition of the Product, From figure 6 could be seen that the total of cycloparaffin and n-paraffin was 50.29 at 250°C but if it was reviewed that yield on 250°C was so little compared to yield of another variable. From a temperature of 300°C total amount of cycloparaffin and n-paraffin continue increase to a temperature of 400°C. It shows that the higher temperature of the pyrolysis the better composition of liquid product.

For the result of gas product composition could be seen at **figure 7**. It shows that the methane composition increase from 5.2% at 250°C into 7.4% at 400°C. It was due to the higher the temperature the higher the energy given and will cause more of light fraction that produced. So can be conclude that higher temperature of the pyrolysis the better composition of gas product and the best temperature is 400°C

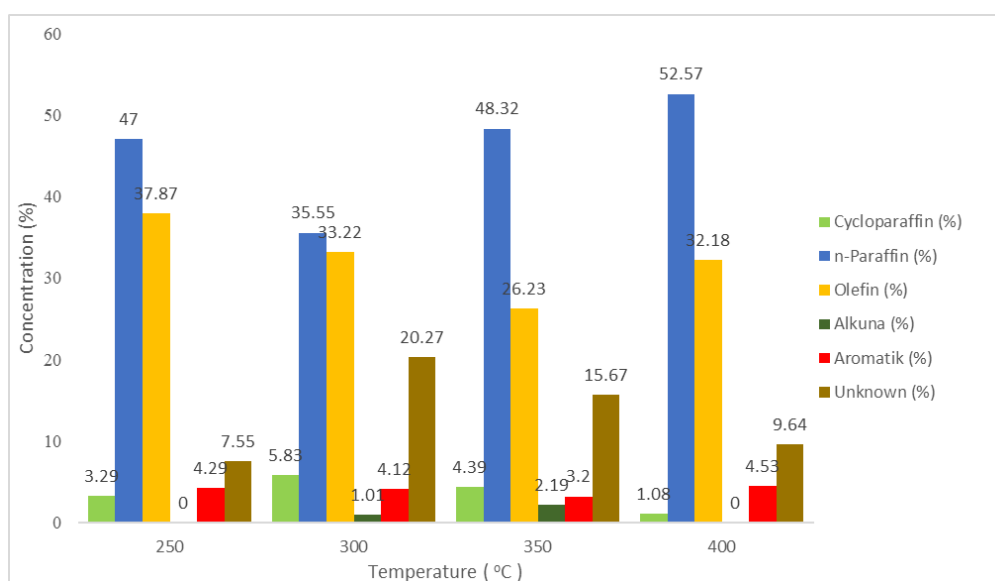


Figure 6. Effect of temperature on composition of the liquid product.

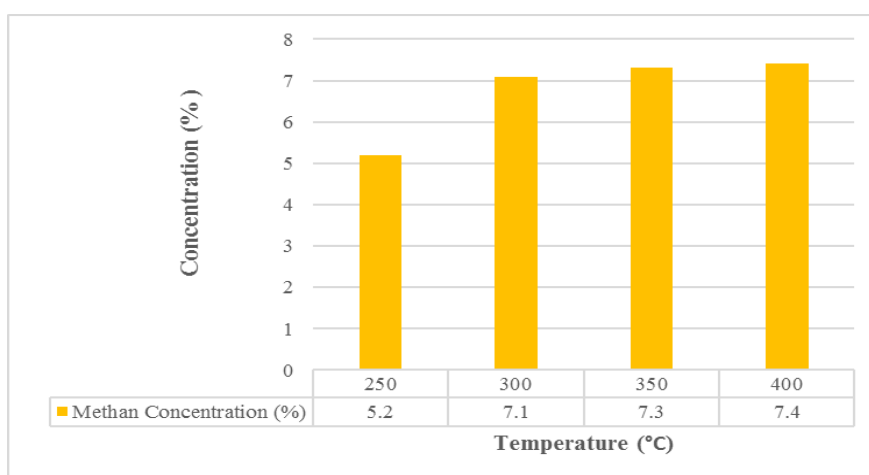


Figure 7. Effect of temperature on methane concentration.

3.4 Effect of Feed to Catalyst Weight Ratio on the Results In the research to determine the effect of the catalyst ratio, the operation time and temperature were determined at 45 minutes and 400°C. Temperature will affect both yield and the composition of product.

3.4.1 Effect of Feed to Catalyst Weight Ratio on Yield of the Product, Figure 8 shows the yield change in each feed to catalyst weight ratio variable. The yield of the liquid product continues to decrease as the number of catalyst ratios increases while the yield of gas product continues to increase as the number of catalyst ratios increase. It happens because with increases of the amount of the catalyst will increase efficiency of heating process and help of pyrolysis cracking process to produced lighter fraction product which is more inclined to from gas and make a better composition of liquid product [3]. The best result was found in the 1:1 feed to catalyst weight ratio which is has 36.58 gram/gram feed yield of liquid product, 62.64 gram/ gram feed yield of as product and 0.78 gram/gram feed yield of residue.

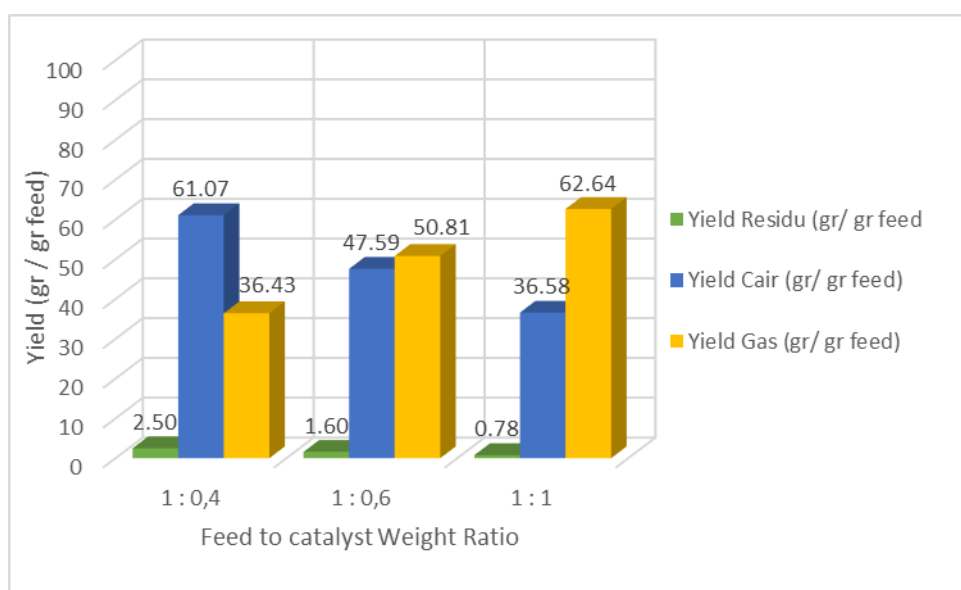


Figure 8. Effect of feed to catalyst weight ratio on yield of the product.

3.4.2 Effect of Feed to Catalyst Weight Ratio on Composition of the Product, From figure 9. can be seen that the quality of the liquid product continues to be better by the higher amount of catalyst that used. Best result is at 1:1 feed to catalyst weight ratio: catalyst with total amount of cycloparafin and n-paraffin is 54.09%.

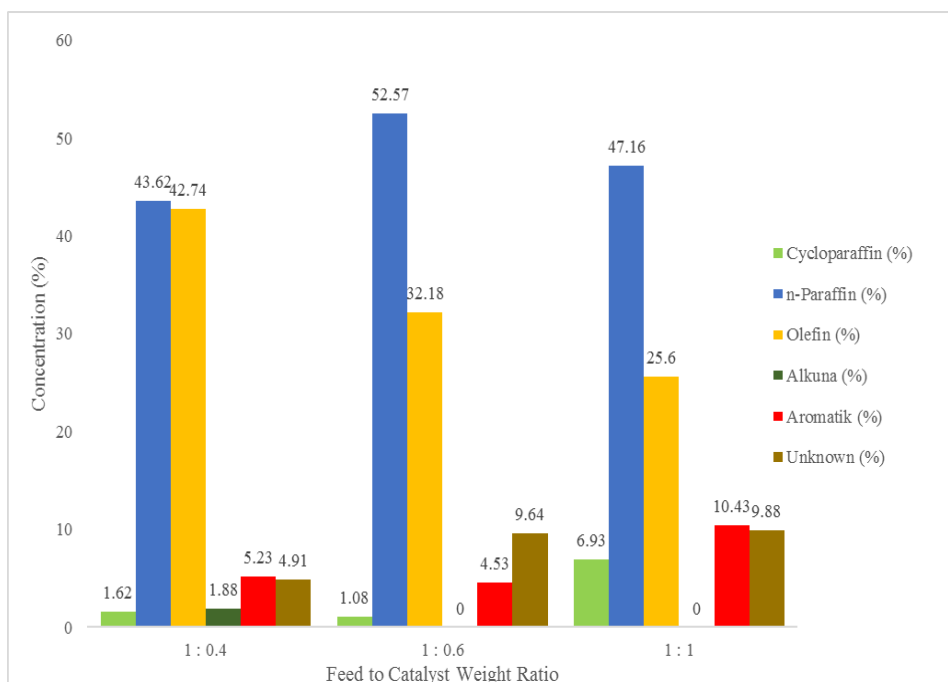


Figure 9. Effect of feed to catalyst weight ratio on yield of the product.

For the effect of the ratio catalyst to concentration of methane of the gas product could be seen at figure 10. The concentration of methane continues to increase by the increases of the ratio of catalyst with the best result at 1:1 feed to catalyst weight ratio which was 10.2 % concentration of methane.

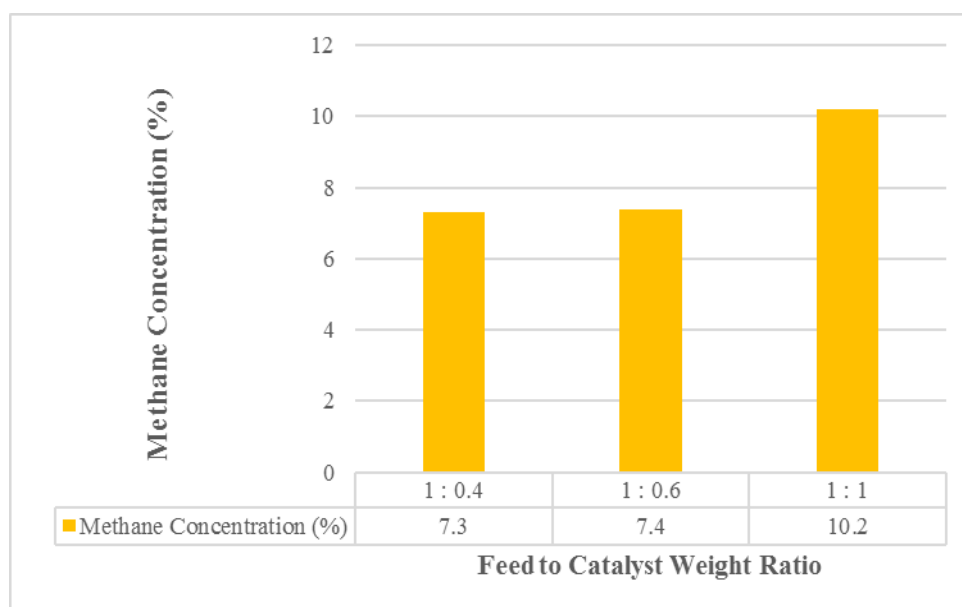


Figure 10. Effect of feed to catalyst weight ratio on methane concentration.

4. Conclusion

In this research can be conclude that HDPE plastic waste can be treat with microwave heating method pyrolysis to produce alternative fuels. Best result obtained at 400°C temperatures of operations with 1:1 feed to catalyst weight ratio for 45 minutes of operation time with results; 36.58 gram/gram feed yield of liquid product, 62.64 gram/gram feed yield of gas product, 0,78 gram/gram feed yield of residue, 54.09% desired liquid product composition and 10.2% methane concentration of gas product.

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