Design and fabrication of integration of organic-inorganic waste pyrolysis equipment

R Sigalingging¹, E Susanto¹, S Panggabean¹ and K I J Munte¹

¹Department of Agricultural Engineering, Universitas Sumatera Utara, Prof. A. Sofyan No. 3 Kampus USU, Medan, Indonesia 20155

E-mail: riswanti@usu.ac.id or riswanti.rs@gmail.com

Abstract. Rice husk is the major by-product of the rice-milling industries and is abundantly available in Indonesia. The study focused on the design and fabrication of integration of organic and inorganic waste pyrolysis equipment as an effort in finding the utilization of heat waste of rice husk burning to convert plastic to be oil fuel. It is an alternative solution to increase energy efficiency and convert waste plastics into a resource. The reactor was used to process 3,000 g plastics and around 11,000 g rice husks per batch. The result showed that temperature around 83-705 °C at rice husk reactor and 151-201 °C at waste plastics reactor continuous process. The pyrolysis process of 3,000 g plastics (gunny bags) was completed in 360 minutes to produce 54.33 g of fuel. This fact shows that the pyrolysis process of plastics can produce fuel at 151 °C in the reactor. Test result showed that the equipment was functional with the equipment’s effective capacity of oil production (ml hour⁻¹) of 49.93; oil conversion efficiencies were 1.81 % (plastic) and 1.87 % (rice husk); waste reduction efficiencies were 27.78 % (plastic) and 76.91 % (rice husk), while oil recovery was 22.43 ml oil kg⁻¹ (waste plastic) and 18.95 ml oil kg⁻¹ (rice husk).

1. Introduction
Energy recovery through waste-to-energy processes has contributed to this change. Although it has a low priority in the waste management hierarchy, it can provide an effective means of organic and inorganic treatment, sustainable energy generation and resource recovery [1]. Organic waste such as rice husk is the major by-product of the rice-milling industries and is abundantly available in the tropical country especially Indonesia. On the other hand, plastic pollution is a serious and growing issue in Indonesian rivers and coastal seas. Indonesia is the second largest source of plastic waste dumped into the sea worldwide [2]. To halt plastic pollution in Indonesia, it is important to alter the country’s land-based waste management system.

Pyrolysis is the decomposition of thermochemical materials at high temperatures and the absence of oxygen or an inert gas atmosphere. Currently, pyrolysis is gaining attention because of its flexibility to produce a combination of solid, liquid and gas products in different amounts by only varying the operating parameters such as temperature or heating rate. This also makes it possible to convert materials from low energy density to high energy bio-fuel densities and recover higher value chemicals [3, 4, 5]. The waste plastic oil converter employs the pyrolysis method of converting waste plastics into oil. The possibility of enhanced recycling in the pyrolysis process, because the products produced such as gas and liquid can be used as a combustible fuel to replace fossil fuels [7]. At present, various types of pyrolysis have been developed: fast, catalytic fast, medium, slow, vacuum. Besides, various types of reactors have been investigated. One of the great advantages of this process is that many types of raw
materials can be used, including industrial and domestic residues. The prerequisite for a successful pyrolysis application is the choice of the right input material and the optimal setting of process conditions. For this reason, the suitability or incompatibility of certain types of waste and their mixtures for the pyrolysis process are verified by laboratory experiments many times with an assessment of the quantity and quality of each pyrolysis product [3, 6].

Therefore, this study aimed to design a reactor by the integration of organic and inorganic pyrolysis plastic and rice husk pyrolysis reactor into single unified equipment. The integration of this pyrolysis utilizes the heat combustion of husks to heat the reactor tube of plastic pyrolysis. Linking pyrolysis of organic and inorganic in an integrated waste treatment process can reuse the heat waste, which means that it potentially increases the overall energy yield and the opportunities for energy recovery from waste.

2. Design and fabrication of integration of organic and inorganic pyrolysis reactor

By integrating plastic and rice husk pyrolysis equipment, it is expected to reduce production costs for plastic pyrolysis. Rice husks deserve to be used as fuel because heat values are higher. The final results that can be utilized from the plastic-rice husk pyrolysis process are three types, namely liquid smoke, husk ash, and fuel from plastic. The plastic will be hydrolysed if the temperature in the reactor is high enough. Pyrolysis gas is channelled into a condenser spiral pipe to be condensed.

![Figure 1. The schema of integration of plastic-rice husk pyrolysis process.](image)

2.1. Experimental design

Designing process was based on determining the dimensions of components of the pyrolysis prototype. This pyrolysis consists of a reactor chamber as a place for plastic pyrolysis, a rice husk pyrolysis chamber, and has a heat-retaining blanket, and also two condenser devices for vapour of plastic and rice husk. The fire-tube heating reactor system of the pyrolysis unit was designed on the basis of the size of the system. It was designed so that sufficient amount of feed material could be taken into it, and in a way that there would be a short vapour residence time in the reactor, which would promote a high yield of pyrolysis liquid product. The selection of the size of the fixed-bed reactor depended upon the amount of feed taken into the reactor. For maximum liquid production, the residence time of the mixture of volatile liquids and gases produced is very important. For simplicity of design, a cylindrical reactor was considered. Due to the corrosive nature of the pyrolytic liquid, stainless steel was used as a reactor material.

The plastic reactor was designed a tube for 3 kg capacity of plastics (gunny bag) waste and a pipe at the top of the reactor was connected to the spiral pipe of the condenser to convert the vapour/gas to be oil/fuel. The plastic reactor’s height was 850 mm, while the diameter was 300 mm. The pyrolysis
chamber of rice husk was designed in tubular form and a pipe at the top was also connected to a spiral pipe as a condenser of vapour of husk rice smoke, while in the middle part was a space for plastic reactor tubes. The rice husk was feeder in the pyrolysis chamber of the funnel. The amount of rice husk that entered the time union was arranged through a hopper. The rice husk reactor with a capacity of 10 kg was 950 mm height, while the diameter was 600 mm. This reactor had two-hopper with 300 mm diameter and 200 mm length which was connected to a through type feeder, 60 mm in diameter. This design is expected to increase the efficiency of heat usage. The bottom of the chaffy pyrolysis chamber was provided an ash filter and a cone for ash collecting; the size of the ash filter was made according to the size of the rice husk ash particles. Also, at the bottom of the rice husk reactor, there was another gate of 150 mm height and 200 mm width for ash removal and starting fire. A blower 2 inch to supply oxygen needs with speed reducer was used in the combustion process; the hot feeder requires oxygen by maximum speed 25 m s\(^{-1}\).

![Figure 2. The complete design views.](image)

The condenser tube was 150 mm diameter and 1000 mm length. Inside the condenser tube had a spiral pipe (helical coil) from stainless steel pipes with 980 mm height and the bending radius was 60 mm (21 fold). The complete design isometric view is shown in figure 2, which are hopper (1), plastic’s reactor (2), pipe connecting (3), thermocouple (4), rice husk’s reactor (5), condenser tube for vapour of plastic (6), condenser tube for vapour of husk smoke(7), blower (8), ash cone (8) and supporting device (10).

2.2. Fabrication and testing pyrolysis equipment

Pyrolysis process was the basis in the design and fabrication of the equipment. It is a prototype/laboratory scale model that will serve as a baseline in developing technology for energy recovery from waste plastic and rice husk. The main components were the reactor assembly, condensing chamber, vapour line assembly, and ash collecting unit as shown in figure 3. Before the testing was made, feedstock was prepared and weighed accordingly. Nine kilograms of type Polystyrene plastic was cut into small pieces and divided into three samples weighing 3 kilograms each. Forty point five kilograms of rice husk was used with 7 % of moisture content wet basis as a heat resource with divided into three samples weighing 10 kilograms each and added after 30, 60, 90 and 150 minutes. The liquid product (oil fuel, smoke liquid), char and ash was collected. In order to understand the temperature distribution in the reactor, eleven thermocouples were placed to measure temperature at the bottom and the top of the reactor as well as in the middle, with the different position from rice husk reactor’s base of each thermocouple of 75 cm (T1), 21 cm (T2), 60 cm (T3), 16 cm (T4), 93 cm (T5), 42 cm (T6), 54 cm (T7), 12 cm (T8) and 107 cm (T9), respectively. The temperature outside the reactor and the condenser was also measured. Data acquisition recorded all temperature data by temperature data logger by connecting.
to a personal computer. Testing was done for three trials to collect data for performance evaluation of the equipment.

Figure 3. Installation complete components of pyrolysis equipment.

In this research, the performance of the fabricated integration of organic and inorganic pyrolysis device was evaluated in terms of the effective capacity of equipment, $C_e$ (ml hour$^{-1}$, equation 1), conversion efficiency or yield oil, $Y_{oil}$ (wt %, equation 2), waste reduction efficiency, $WR_e$ (wt %, equation 3), oil recovery, $O_{rec}$ (ml of oil kg$^{-1}$ of plastic or rice husk, equation 4) and expressed by the following formula.

$$C_e = \frac{\text{Volume of oil plastic converted (ml)} + \text{Volume of oil rice husk converted (ml)}}{\text{time (hour)}}$$  \hspace{1cm} (1)

$$Y_{oil} = \frac{\text{Mass of oil plastic (rice husk) converted (g)}}{\text{Mass of sample materials (g)}} \times 100 \%$$ \hspace{1cm} (2)

$$WR_e = \frac{\text{Mass of sample materials (g)} - \text{Mass of char (ash) (g)}}{\text{Mass of sample material (g)}} \times 100 \%$$ \hspace{1cm} (3)

$$O_{rec} = \frac{\text{Volume of oil plastic(rice husk) converted (ml)}}{\text{Mass of sample materials (kg)}}$$ \hspace{1cm} (4)

3. Results and discussion

The design and fabrication of the integration of organic-inorganic pyrolyser is the major part of this project work and maximum time has been spent to design, construct and assemble the experimental setup. Table 4 shows the value of 49.93 ml hour$^{-1}$ per batch process equipment’s effective capacity on oil production. This capacity is a measurement of the amount of performance that occurred. The evaluation of an equipment’s capacity is an important evaluation because underutilization of a machine increases the production costs and overutilization can lead to increasing repair, maintenance costs, and shorten machine life. Engineers continue to strive to improve the operating efficiency by reducing energy and/or waste requirements from agricultural and manufacturing processes. When referring to machinery/equipment, efficiency is an evaluation of how well a machine does the tasks designed to perform. The concept of efficiency is to evaluate how well a machine performs its designed task regarding quantity and/or quality of performance. Mechanical efficiency is related to how well the machine converts energy from one form to another [8].
Table 1. The value of equipment’s effective capacity on oil production.

| Repetition | Volume of plastic’s oil (ml) | Volume of rice husk’s oil (ml) | Time (hour) | Effective capacity of equipment, $C_e$ (ml hour$^{-1}$) |
|------------|-----------------------------|--------------------------------|-------------|--------------------------------------------------|
| 1          | 60                          | 111                            | 6.15        | 27.80                                            |
| 2          | 67                          | 90                             | 6.00        | 26.17                                            |
| 3          | 75                          | 500                            | 6.00        | 95.83                                            |
| Total      | 202                         | 701                            | 18.15       | 149.8                                            |
| Rate       | 67.3                        | 233.6                          | 6.05        | 49.93                                            |

The value of oil yield or conversion efficiency and oil recovery of plastic waste is displayed in Table 2 while for rice husk is shown in Table 3. Based on the result of the study, the waste plastic and rice husk oil converter have a 1.81 % and 1.87 % oil yield or conversion efficiency (Table 2 and 3). This value shows the ability of the equipment to convert waste plastic into oil regarding weight. On the other hand, the waste plastic and rice husk oil converter could recover 22.43 ml and 18.95 ml of oil per kilogram of waste plastics and rice husks, respectively. This oil recovery is the measure of how much oil the equipment can recover per kg of waste plastic.

Table 2. The values of oil yield, waste reduction efficiency and oil recovery of plastic waste.

| Repetition | Mass of plastic waste (g) | Mass of plastic oil (g) | Mass of char (g) | Oil yield, $Y_{oil}$ (%) | Waste reduction efficiency, $WR_e$ (%) | Oil recovery, $O_{rec}$ (ml kg$^{-1}$) |
|------------|---------------------------|-------------------------|------------------|--------------------------|---------------------------------------|-------------------------------------|
| 1          | 3000                      | 46.73                   | 2200             | 1.56                     | 26.67                                 | 20.0                                |
| 2          | 3000                      | 55.52                   | 2200             | 1.85                     | 26.67                                 | 22.3                                |
| 3          | 3000                      | 60.75                   | 2100             | 2.02                     | 30.00                                 | 25.0                                |
| Total      | 9000                      | 163.00                  | 6500             | 5.43                     | 83.34                                 | 67.3                                |
| Rate       | 3000                      | 54.33                   | 2166.67          | 1.81                     | 27.78                                 | 22.43                               |

Table 3. The values of oil yield, waste reduction efficiency and oil recovery of rice husk.

| Repetition | Mass of rice husk (kg) | Mass of rice husk oil (g) | Mass of ash (kg) | Oil yield, $Y_{oil}$ (%) | Waste reduction efficiency, $WR_e$ (%) | Oil recovery, $O_{rec}$ (ml kg$^{-1}$) |
|------------|------------------------|---------------------------|------------------|--------------------------|---------------------------------------|-------------------------------------|
|            | white                  | grey                      | black            | unburnt                  |                                       |                                     |
| 1          | 16.0                   | 110.9                     | 0.19             | 2.00                     | 0.00                                  | 4.00                                | 0.69                                 | 81.75                                 | 6.94                                  |
| 2          | 14.0                   | 89.4                      | 0.35             | 2.15                     | 0.15                                  | 3.00                                | 0.63                                 | 75.90                                 | 6.43                                  |
| 3          | 11.5                   | 495.5                     | 0.31             | 1.70                     | 1.00                                  | 0.00                                | 4.30                                 | 73.83                                 | 43.48                                 |
| Total      | 41.5                   | 163.0                     | 0.85             | 5.85                     | 1.15                                  | 7.36                                | 5.62                                 | 230.73                                | 56.85                                 |
| Rate       | 13.83                  | 54.33                     | 0.28             | 1.95                     | 0.38                                  | 2.45                                | 1.87                                 | 76.91                                 | 18.95                                 |

The waste reduction of waste plastics and rice husk of equipment (Tables 2 and 3) are 27.78 % and 76.91 %, respectively. This waste reduction efficiency is the measure of how efficient the equipment in reducing waste regarding weight which is calculated by subtracting the weight of char from the original weight of the plastic and/or rice husk and divided by the original weight of the plastic and/or in percentage.
The 8th International Symposium for Sustainable Humanosphere
IOP Conf. Series: Earth and Environmental Science 374 (2019) 012015
doi:10.1088/1755-1315/374/1/012015

Table 4. The position of each thermocouple from rice husk reactor’s base.

| Repetition | T1   | T2   | T3   | T4   | T5   | T6   | T7   | T8   | T9   |
|------------|------|------|------|------|------|------|------|------|------|
| 1          | 138.4| 589.0| 120.6| 728.1| 108.1| 108.7| 109.0| 394.1| 201.0|
| 2          | 83.5 | 483.1| 82.1 | 763.3| 128.4| 104.6| 83.5 | 557.5| 151.0|
| 3          | 115.5| 705.6| 118.8| 693.2| 108.5| 360.4| 80.2 | 577.1| 182.6|

The position of each thermocouple of 75 cm (T1), 21 cm (T2), 60 cm (T3), 16 cm (T4), 93 cm (T5), 42 cm (T6), 54 cm (T7), 12 cm (T8) and 107 cm (T9) from reactor’s base.

In order to achieve the complete conversion of oil, it is desirable to increase a low temperature (table 4) at plastic reactor (T9) and at rice husk reactor (T1, T3, T5, T6 and T7) during pyrolysis and/or partial combustion of rice husk, followed by steam pyrolysis in either case. On the other hand, T2, T4, and T8 were higher than T1, T3, T5, T6, and T7 meaning the air flow of 25 m s⁻¹ affected to the combustion flow rate of rice husk. The addition of rice husk during the pyrolysis process also affected the combustion process in the reactor room. In another study using this equipment, the combustion temperature was beyond 900°C without adding rice husks and sometime could be over 1000 °C. According to Ganesh et al. [9] that in the partial combustion of any biomass, the processes of pyrolysis, gasification, thermal cracking, and combustion normally take place simultaneously and lead to a complex situation, hot spots invariably develop and husk ash becomes subjected to temperatures beyond 900°C.

Figure 4. The temperature distribution in plastics reactor and rice husk reactor of 6 hours process.

4. Conclusions

Pyrolysis integration equipment for organic-inorganic waste can be used as a pyrolizer tool of rice husks and plastics waste as well as the utilization of heat from rice husk. This tool produced three products that can be utilized, namely fuel from plastic waste, liquid smoke and rice husk ash which varies in colour (white, grey and black). The reactor was used to process 3,000 g plastics and around 11,000 g rice husks per batch. The result showed that temperature was around 83-705 °C at rice husk reactor and
151-201 °C at waste plastic reactor continuous process. The pyrolysis process of 3,000 g plastics (gunny bags) was completed in 360 minutes to produce 54.33 g of fuel. This fact shows that the pyrolysis process of plastics can produce fuel at 151 °C in the reactor. Test result showed that the equipment was functional with equipment’s effective capacity for oil production (ml hour⁻¹) of 49.93; oil conversion efficiencies were 1.81 % (plastic) and 1.87 % (rice husk); waste reduction efficiencies were 27.78 % (plastic) and 76.91 % (rice husk) while oil recovery was 22.43 ml oil kg⁻¹ (waste plastic) and 18.95 ml oil kg⁻¹ (rice husk). Research is being carried out to improve the performance of this tool.

Acknowledgments
The research was funded by Directorate of Research and Community Service, Directorate General of Development and Research Enhancement, Ministry of Research, Technology and Higher Education of Republic of Indonesia (DRPM 2018 with Number: 103/UN5.2.3.1/PPM/KP-DRPM/2018 on 5th February 2018).

5. References
[1] Yang Y, Heaven S, Venetsaneas N, Banks C J and Bridgwater 2018 Slow pyrolysis organic fraction of municipal solid waste (ofmsw): characterisation of products and screening of the aqueous liquid product for anaerobic digestion Applied Energy 213 158-168
[2] Jambeck J R, Geyer R, Wilcox C, Siegler T R, Perryman M, Andrady A, Narayan R and Law K L 2015 Plastic waste inputs from land into the ocean Science 347 (6223) 768-771
[3] Czajczynska D, Nannou T, Anguilano L, Krzyzynska R, Ghazal H, Spencer N and Jouhara H 2017 Potentials of pyrolysis processes in the waste management sector Energy Procedia 123, 387-394
[4] Chowdhury R and Sarkar A 2012 Reaction kinetics and product distribution of slow pyrolysis of Indian textile wastes International Journal of Chemical Reactor Engineering 10 (1) A67
[5] Biswal B, Kumar S and Singh R K 2013 Production of hydrocarbon liquid by thermal pyrolysis of paper cup waste Journal of Waste Management 2013 1–7
[6] Grycová B, Koutník I, Prysiezch A and Koloč M 2016 Application of pyrolysis process in the processing of mixed food wastes Polish Journal Chemical Technology 18 (1) 19–23
[7] Rapsing E C 2016 Design and fabrication of waste plastic oil converter International Journal of Interdisciplinary and Innovations 4(2) 69-77
[8] Field H L and Solie J B 2007 Equipment Efficiency and Capacity. In: Introduction to Agricultural Engineering Technology Springer Boston MA
[9] Ganesh A, Grover P D and Iyer P V R 1992 Combustion and gasification characteristics of rice husk FUEL 71 889-894