Vol. 14 Special Issue (2023) 12-20

Jurnal Riset
Teknologi Pencegahan Pencemaran Industri

Journal homepage : https://www.jrtppi.id

Kementerian Perindustrian REPUBLIK INDONESIA

The Processing of LDPE Plastic Waste into Renewable Fuel Using Waste Motor Oil

Alex Surapati*[1], Angky Puspawan[1], Yanolanda Suzantry Handayani[1], Fitrilina[1]

[1] Universitas Bengkulu, Bengkulu 38371, Indonesia.

A R T I C L E I N F O

Article history:
Received March 31, 2023
Received in revised form June 06, 2023
Accepted July 20, 2023
Available online December 22, 2023

Keywords :
Plastic Waste
Oil Waste
Processing Machines
Renewable Fuel

A B S T R A C T

The increase in population causes an increasing amount of solid waste, especially plastic waste. Plastic waste that cannot be decomposed in nature increases its number and causes environmental pollution. This research aimed to process plastic waste into alternative fuel oil using waste motor oil. The research methods consisted of designing a plastic waste processing device using waste motor oil as fuel and testing the device with a plastic burning process using a processing machine. The plastic waste processing device was produced as a stove to heat plastic waste fueled by waste motor oil using an electric blower to generate pressure into the reactor. The heating process produces steam flowing and processing in a distillation tube to produce oil. LDPE plastic waste could produce renewable fuel at the temperature of 140^{o}C, but there were still burning residues. The distillation produced two types of fuel oil, yellow and black.

1. INTRODUCTION

The Hygiene and City Parks Service of Bengkulu City stated that the amount of transported waste each day is 600 m^3, with detail of 700 m^3/day in total, in which 600 m^3 is transported to Temporary Landfill (henceforth TPS – Tempat Pembuangan Sementara), and the rest is piled up, burned, or heaped in Final Processing Landfill (henceforth TPA – Tempat Pembuangan Akhir). Some waste is disposed of by the community in illegal TPS (Wijaya, Alfansi, & Benardin, 2013). The population growth in Bengkulu Province impacts increasing the amount of solid waste. Bengkulu City has an area of 14,482 Ha with a population of 360,772 people producing 1,082.32 m^3 of waste daily (Ronal, 2015).

The composition of the waste produced by human activities is organic waste (60-70%) and non-organic waste (30-40%). Furthermore, the second most significant component of non-organic waste is plastic waste, with a 14% percentage (Purwaningrum, 2016). The majority of plastic waste is the plastic bag and plastic packaging.

The use of plastic products that are not environmentally friendly causes various severe environmental problems (Krisyanti & Priliantini, 2020). Plastic is a versatile product, light, flexible, moisture resistant, strong, and relatively inexpensive (Fatimura, Sepriyanti, & Yunita, 2019). The characteristic of plastic is considered to provide convenience in daily human activity. Although it is considered practical and economical, plastic can cause plastic waste, which is very dangerous for the environment and its components (Utami & Ningrum, 2020). The danger is that plastic waste is a challenging waste to manage.

Plastic is a macromolecule formed by a polymerization process: assembling several simple molecules (monomers) through a chemical process into large molecules called polymers (Surono & Ismanto, 2016).

*Correspondence author.
E-mail : alexsurapati@gmail.com (Alex Surapati)

doi : https://10.21771/jrtppi.2023.v14.si.p12-20

Accreditation number : (Ristekdikti) 158/E/KPT/2021

Plastic is a polymer compound whose main constituent elements are Carbon and Hydrogen (Bow, Zulkarnain, Sihombing, Kharissa, & Salam, 2018; Surono & Ismanto, 2016). One of the raw materials often used is naphtha, a material produced from refining petroleum or natural gas (Surono & Ismanto, 2016). Furthermore, producing 1 kg of plastic requires 1.75 kg of petroleum to meet the needs of raw materials and the energy of the process (Ramanda & Dewiyani, 2022).

Indonesia is in second place in the world for dumping plastic waste into the sea at a rate of 0.52 kg of waste/person/day or equivalent to 3.22 MMT/year (Jambeck, Geyer, & Law, 2015). Plastic waste is a type of waste that cannot be decomposed, so if the waste is not managed correctly, it will cause environmental pollution.

Plastic waste is a source of problems because it cannot absorb water, decompose, or be degraded in the soil (Yana & Badaruddin, 2017). Plastic waste is an inorganic waste that is difficult to decompose in the soil. Plastic waste takes 50-80 million years to decompose. However, plastic waste has economic value as an energy source because plastic comes from petroleum (Bow et al., 2018; Kumar, Panda, & Singh, 2011). With a proper process, plastic waste can be produced into hydrocarbons as a primary energy source (Aditama, 2018).

Waste processing is an effort to reduce the volume of waste or change its form to become more valuable products by burning, composting, destroying, drying, and recycling the waste (Anonim, 2002). Recycling plastic waste can be conducted in various ways, such as turning plastic waste into attractive accessories and handicrafts. Moreover, with the advancement of science, plastic waste can be converted into fuel oil (henceforth BBM – Bahan Bakar Minyak) (Oktora, Alwie, & Utari, 2019; Wajdi, Sapiruddin, Novianti, & Zahara, 2020). The recycling process is conducted by converting the plastic waste into fuel, considering that the raw plastic material comes from petroleum derivatives. Then the plastic waste can be returned to hydrocarbon form as a primary energy source.

This research problem is that the processing of plastic waste into renewable fuel using waste motor oil in Bengkulu City still needs to be created. For this reason, a plastic waste processing machine with waste motor oil in the combustion process is needed.

The plastic used as research material was Low-Density Polyethylene (LDPE), which can be processed through heating. This type of plastic is made from petroleum and has been produced since 1933. This type of plastic is relatively thin, flexible, clear, and light. In daily life, this plastic is widely used by traders to pack their wares, and in households, it is used as garbage bags, shopping bags, plastic wrap/packaging, and multi-purpose plastics such as ziplock.

This LDPE plastic has long durability and can be used repeatedly, so the plastic obtained from the market can still be used for other purposes. Ideally, this type of plastic is only used once and recycled because it takes hundreds of years to decompose. Plastic waste in Bengkulu City has increased by 10% since 2022. The estimation from the Bengkulu City Environmental Service based on the current population, the amount of waste reaches 765 cubic meters. In contrast, the handled amount is approximately 485 cubic that goes to the final processing landfill (TPA).

Currently, many plastic waste processing devices can convert plastic waste into various products, for instance, crude oil, gasoline, diesel, premium, and kerosene, with some processes (Oktora et al., 2019). However, the processing still uses a heating system using fossil fuels, so the impression of saving energy still needs to be achieved (Abdullah, Irawati, Qomariah, & Ain, 2020).

The increase in the fossil fuel price and the scarcity of certain types of fuel have resulted in long queues of vehicles at various public gas stations (henceforth SPBU – Stasiun Pengisian Bahan Bakar Umum). The price adjustment was based on the Decree of the Minister of Energy and Mineral Resources Number 62 K/12/MEM/2020 on the Basic Price Formula in Calculation of the Retail Selling Price for General Oil Fuel Types of Gasoline and Diesel Oil Channeled through Public Gas Stations. Based on this condition, it is necessary to innovate the fuel oil processing from plastic waste with environmentally friendly technology.

The process of processing waste into fuel includes several processes, such as: (1) pyrolysis is the chemical decomposition of organic matter through a heating process without or little oxygen or other chemical reagents in which the raw material will undergo a breakdown of the chemical structure into a gas phase (Riandis, Setyawati, & Sanjaya, 2021). The pyrolysis process will break down long hydrocarbon chains from plastic polymers into short hydrocarbon chains. Then these molecules are cooled into a liquid phase (Nasrun, Kurniawan, & Sari, 2015; Ridhuan, Irawan, & Inthifawzi, 2019). Pyrolysis, a thermochemical process that occurs in an oxygen-free environment (Fombu & Ochonogor, 2021), has been used for charcoal production for many years (thousands of years).

Pyrolysis is used to convert waste products into biofuel, producing little or no waste after the process is carried out (Fombu & Ochonogor, 2021; Jahirul, Rasul, Chowdhury, & Ashwath, 2012), thereby causing the method to get more attention nowadays compared to other thermo-chemical conversion processes. The insulating chamber was designed to have a length of 20.3 cm, a width of 20.3 cm, and a height of 34.0 cm (Fombu & Ochonogor, 2021). This chamber was located between the heating chamber and the reactor's external body (having a height of 50.0 cm and diameter of 31.8 cm); (2) Distillation is the separation of a mixture in a solution based on boiling point differences (Nasrun et al., 2015).

The construction of plastic waste processing machines uses the principle of pyrolysis and multilevel distillation, in which the plastic will be processed in a reactor heated with methane gas (Prasetya, Rudhiyanto, & Fitriyanto, 2017). Pyrolysis, a thermochemical process that occurs in an oxygen-free environment, has been used for charcoal production for many years (thousands of years). The result of a previous study was a waste processing machine with a specification of 1 m long, 0.35 m wide, 1.35 m high, 30 kg weight, and 0.5 litres/30 minutes production capacity. Mass production of the machine can reduce the amount of plastic waste, but decreasing methane gas worldwide creates new problems (Prasetya et al., 2017).

Fuel oil (BBM) from plastic waste is produced by distillation. The pyrolysis process is carried out to melt and evaporate plastic waste in the reactor. First, the raw materials or plastic waste are cleaned and chopped. Then, the material is placed into the reactor through the input hole. In addition, the reactor is heated using a furnace fueled by liquefied petroleum gas (LPG) (Sumartono, Ibrahim, & Sarjianto, 2018).

This research aimed to make a plastic waste processing machine to process the plastic waste into renewable fuel oil using used waste motor oil. The motor oil used for engine maintenance will produce waste motor oil. In line with the development of cities and regions, the volume of waste motor oil continues to increase along with the number of motorized vehicles and machines (Azharuddin, Sani, & Ariasya, 2020).

Using motorized vehicles has various effects on environmental damage; one of the effects is pollution due to the waste of motor oil. Toxic waste (B3 – Bahan Berbahaya Beracun) is substances, energy, or other components that, due to their characteristic, concentration, or amount, either directly or indirectly, can pollute or damage the environment or endanger the environment, health, and sustainability of the human life and other living objects (Anonim, 2014; Azharuddin et al., 2020).

The toxic waste contains substances that pollute the air, water, and soil (Candra, Sulastry, & Anwar, 2016). This pollution will harm the environment if it is not recycled. One litre of waste motor oil can damage millions of litres of water sources in the soil, causing the soil to lose its nutrients (Herdito, Risna, & Lutfi, 2021). The environmental pollution due to waste motor oil has been widely reported in the mass media. The waste motor oil has substances of combustion residues that are acidic, corrosive, deposits, and carcinogenic heavy metals. The waste of motor oil is extensive, so special treatment is needed (Rubiono & Yasi, 2017).

Heretofore, the community's use of waste motor oil still needs to be improved, especially as fuel. The utilization of waste motor oil has yet to be maximized due to the absence of a suitable and perfect device to utilize waste motor oil as fuel for the community (Hidayat & Basyirun, 2020). The waste motor oil can be used as fuel for stoves in plastic waste-burning (Pratama, Basyirun, Atmojo, Ramadhan, & Hidayat, 2020).

Like diesel or gasoline, waste motor oil cannot achieve complete combustion. It happens because waste motor oil is not flammable, so there is no fogging like fuel in general. Used engine oil, however, has a relatively high calorific value, so it is interesting to be used this waste as a renewable fuel for heat generation. Therefore, the present experimental study has been conducted on used engine oil combustion in a vertical tube burner (Lekpradit & Namkhat, 2017).

2. METHODS

The utilization of waste motor oil in the process of processing plastic waste into alternative fuel oil (BBM) is carried out according to the block diagram in Figure 1 below.

This research is in the form of producing devices/machines for processing plastic waste using waste motor oil as fuel for the stove in the process of burning plastic waste. The conducted stages of this research are: 1) the plastic waste is put into the boiler for the burning process, which then produces steam; 2) the steam flows through a pipe that is immersed in a cooling tube, the result of cooling the steam will produce fuel oil; 3) The testing of the machine will produce renewable fuel oil that can be used as a substitute for fossil fuels. The analysis was carried out to determine how to change the form from gas to liquid fuel oil. The flow chart of this research can be seen in Figure 2 below.

3. RESULT AND DISCUSSION

This research was carried out in some stages, starting from the solid waste collecting in the form of plastic waste and liquid waste in the form of waste motor oil. The used plastic waste is crackle plastic collected from residential and tourist attraction areas, as shown in Figure 3 below.

Besides solid waste, liquid waste in the form of waste motor oil from local automotive workshops also burdens the environment. The waste motor oil was obtained from car workshops which collect the waste motor oil into drums. The waste motor oil contains harmful chemicals such as hydrocarbon and sulfur because of the motor oil's function to lubricate the metals in the engine. In addition, the waste motor oil contains residual fuel, copper, iron, aluminium, magnesium, and nickel that can cause environmental damage if not well treated before being dumped into the environment.

The waste motor oil in this study was used as fuel for the stove, which heat the plastic waste in the reactor. The stove furnace was designed as a cube with a pyramid top. The stove dimensions are 22 cm x 22 cm bottom area, 12 cm x 12 cm top area, and 30 cm total height.

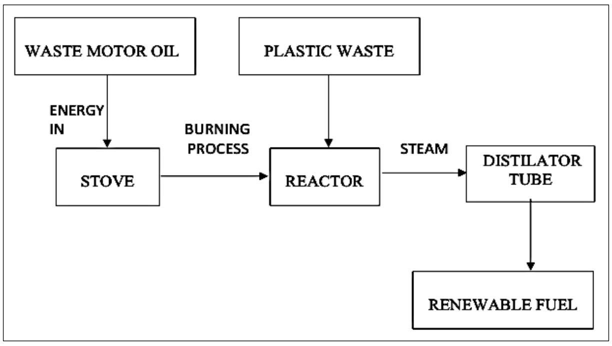

Figure 1. The Block Diagram of Processing Plastic Waste into Renewable Fuel

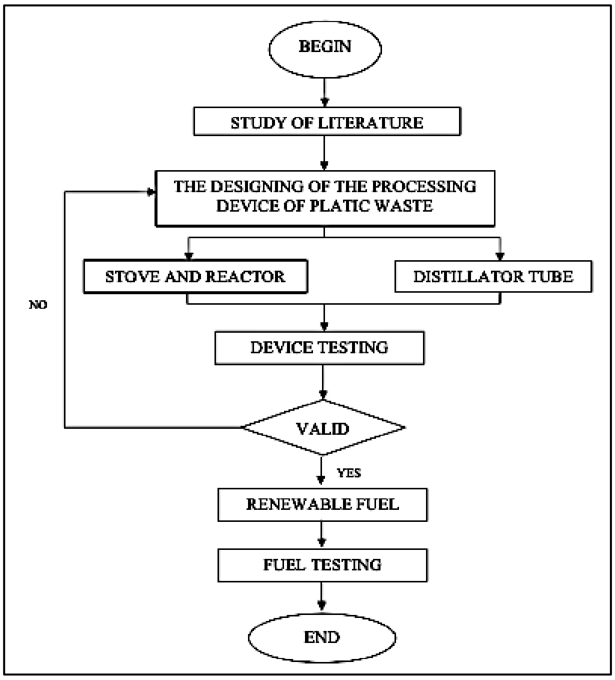

Figure 2. The Research's Flow Chart

Figure 3. The Plastic Waste

Figure 4. The Blower and Stove

Figure 5. The Reactor

Figure 6. The Distillation Tube

Figure 7. The Assembly and Performance Testing of the Device

The furnace was connected to a motor oil tube of 16 cm height for the burning process through a 100 cm long pipe. The tube held the motor oil continuously during the burning process through a pipe connected to an oil reservoir with a dimension of 30 cm x 30 cm and a height of 45 cm. The stove pressure in the heating process was given by an electric blower, as shown in Figure 4.

The next stage was to create a reactor, a furnace, and a distillation set to burn the plastic waste to produce oil. The furnace was designed as a reactor holder, which functions so that the fire generated from the stove can be maintained and the temperature entering the reactor can be constant. The furnace is 63 cm x 63 cm with a height of 44 cm.

The reactor is a device that can convert polypropylene (PP), polyethylene (PE), and polystyrene (PS) plastic waste into fuel oil. It is called the pyrolysis method: heating the plastic above 400°C without oxygen. The plastic will melt at this temperature and then turn into a gas. The gas flows into a distillation tube to cool and produce oil. In this study, the produced temperature in the burning process was only 140°C, so the plastic waste was not entirely decomposed and still produced residue.

Previous research on reactor design for refining tires into oil illustrates tire pyrolysis in a tubular stainless steel batch reactor of diameter D = 0.48 m and height H = 0.99 m. The overall size of the reactor was 2.49 m, and the shield length was 0.61 m (Aziz, Al-khulaidi, Rashid, & Islam, 2016). The process was carried out with maximum liquid production. The reactor wall was made from two 0.002 m stainless steel sheets, with a 0.04 m thick insulation layer (glass wool) between them. At the bottom of the reactor, a 0.20 m diameter tube was attached to remove char. Five spiral tubes of 0.019 m diameter (three U-shaped and two semi-hexagonal) were placed inside the chamber to improve fast heating. However, a fuel burner supplies the primary heat flux to the reactor. This furnace has a hole where the reactor was placed, two openings for supplying solid fuel, and four ports for removing ash.

Figure 8. The distillation process and fuel oil result

In this research, the reactor was designed according to the planned plastic waste (LDPE) capacity of 6 kg. The reactor has a size of 60 cm x 60 cm and a height of 60 cm. The dimensions of the reactor are made based on the capacity to be accommodated by 75 kg of plastic. A box was placed at the front of the reactor to collect the gas obtained from the burning process. The box was connected to the distillation set.

The box was given a connecting pipe from the plastic burning chamber to the gas chamber with a size of 20 cm x 60 cm and a height of 20 cm. In this section, an iron pipe was installed to connect the chamber to the distillation set. The reactor lid was designed to be practical so that it can be opened and closed but still airtight with a size of 40 cm x 33 cm and a height of 10 cm. One of the raw materials for making the reactor was a steel plate with a thickness of 3 mm, as shown in Figure 5.

The gas produced in the burning process flows into the distillation tube. The function of the distillation tube is to cool the gas so that the gas will condense and form a liquid. This liquid will become a renewable fuel. The distillation tube was made as a box with a size of 60 cm x 20 cm, a height of 20 cm, and a tilt position of 45°. The distillation tube was given a pipe that would be connected to the reactor. At the top of the distillation tube, an iron pipe with a stopper was attached. The length of the pipe is 55 cm which functions as a gas exhaust. At the bottom of the distillation tube are 2 (two) pipes on the left and bottom right sides. The pipe with a length of 45 cm was provided with a stopcock that would drain the produced renewable fuel in the cooling process. The height of the distillation tube foot is 83 cm with a width of 53 cm, as shown in Figure 6.

After the equipment was produced, the assembly and testing process was carried out to test the performance feasibility of the device before the actual experiment was conducted. The assembly and testing process of the device can be seen in Figure 7 below.

Following device assembly and testing, observations were conducted on the temperature generated from the stove that can be used to produce steam as needed. The optimum temperature obtained was measured using a thermometer, and the pressure was controlled due to the allowed maximum pressure so that the steam produced could produce oil.

The testing stage was conducted by heating the reactor, filled with plastic waste, and using a stove with waste motor oil fuel. The heat generated by the stove with a blower reached a temperature of 140ºC used to burn the plastic waste. The steam generated from the burning process was cooled through a pipe inserted into a distillation tube that converted the steam into a liquid. From the distillation tube, the resulting fuel oil came out through the faucet and was collected. The distillation results produced water and two types of fuel: yellow fuel and black fuel. The refining process and the fuel oil can be seen in Figure 8.

The produced fuel oil is similar to diesel fuel visually and characteristically in terms of colour and smell. The chemical composition of the produced fuel oil from the refining process will be tested in the laboratory for further research.

3. CONCLUSION

Based on the study's results, it can be concluded that the plastic waste processing machine using waste motor oil as fuel can operate and produce yellow and black alternative fuel oil. In plastic waste processing, the residue remains because the temperature reached in the heating process is only 140°C.

Further research is needed on the reactor material so that the generated temperature is more optimal than the current generated temperature and the heating results leave zero residues. The produced fuel needs to be tested in a laboratory to determine the composition and type of the fuel.

ACKNOWLEDGEMENT

The authors would like to thank the Office of Research and Community Service of The University of Bengkulu for funding this research, with research contract number: 1989/UN30.15/PP/2022 dated 21 June 2022.

REFERENCES

Abdullah, Irawati, U., Qomariah, N., & Ain, N. (2020). Buku Ajar Teknologi Tepat Guna. Mengolah Sampah Plastik Menjadi Bahan Bakar Minyak. (A. Irwan, Ed.) (1st ed.). Banjarmasin: Lambung Mangkurat University Press. Retrieved from https://repo-dosen.ulm.ac.id/bitstream/handle/123456789/17941/Buku mengolah sampah plastik menjadi bahan bakar minyak. Prof Abdullah ...pdf?sequence=1

Aditama, B. K. (2018). Pemanfaatan Sampah Plastik sebagai Bahan Bakar Alternatif Melalui Proses Pirolisis dan Reforming.

Anonim. Tata Cara Teknik Operasional Pengelolaan Sampah Perkotaan SK SNI 19-2452-2002, Departemen Pekerjaan Umum § (2002). Bandung: Citra Aditya Bakti.

Anonim. Peraturan Pemerintah (PP) No. 101 Tahun 2014. Pengelolaan Limbah Berbahaya dan Beracun (2014).

Azharuddin, Sani, A. A., & Ariasya, M. A. (2020). Proses Pengolahan Limbah B3 (Oli Bekas) Menjadi Bahan Bakar Cair Dengan Perlakuan Panas Yang Konstan. Jurnal Austenit, 12(2), 48–53. Retrieved from https://jurnal.polsri.ac.id/index.php/austenit/article/download/2777/1201

Aziz, M. A., Al-khulaidi, R. A., Rashid, M. M., & Islam, M. R. (2016). Design and fabrication of a fixed-bed batch type pytolysis reactor for pilot scale pyrolytic oil production in Bangladesh. In International Conference on Recent Trends in Physics. IOP Publishing Ltd. https://doi.org/10.1088/1742-6596/755/1/011001

Bow, Y., Zulkarnain, Sihombing, S. R. M., Kharissa, S. A., & Salam, Y. A. (2018). Pengolahan Sampah Low Density Polyethylene (LDPE) dan Polypropylene (PP) menjadi Bahan Bakar Cair Alternatif Menggunakan Prototipe Pirolisis Thermal Cracking. Jurnal Kinetika, 9(3), 1–6.

Candra, A., Sulastry, T., & Anwar, M. (2016). Pengaruh Konsentrasi dan Waktu Kontak Pada Adsorpsi Arang Aktif Terhadap Viskositas Oli (Minyak Pelumas) Bekas. Chemica, 17(1), 27–33. Retrieved from https://ojs.unm.ac.id/chemica/article/view/4566

Fatimura, M., Sepriyanti, R., & Yunita, R. (2019). Pengolahan Limbah Plastik Jenis Kantong Kresek dan Gelas Minuman Menggunakan Proses Pirolisis Menjadi Bahan Bakar Minyak, 4(2). Retrieved from https://media.neliti.com/media/publications/318785-pengolahan-limbah-plastik-jenis-kantong-b5eacd84.pdf

Fombu, A. H., & Ochonogor, A. E. (2021). Design and Construction of Semi-batch Pyrolysis Reactor for the Production of Biofuel. In IOP Conf. Series: Earth and Environmental Sciences. San Francisco, CA: IOP Conference Series. https://doi.org/https://doi.org/10.1088/1755-1315/730/1/012041

Herdito, T., Risna, & Lutfi, M. (2021). Pemanfaatan Limbah Oli Bekas Menjadi Bahan Bakar High Speed Diesel (HSD). Sains Terapan, 7(2), 57–63. Retrieved from https://jurnal.poltekba.ac.id

Hidayat, A. R., & Basyirun, B. (2020). Pengaruh Jenis Oli Bekas Sebagai Bahan Bakar Kompor Pengecoran Logam Terhadap Waktu Konsumsi dan Suhu Maksimal Pada Pembakaran. Jurnal Dinamika Vokasional Teknik Mesin, 5(2), 103–108. Retrieved from https://journal.uny.ac.id/index.php/dynamika/article/download/34802/14311

Jahirul, M. I., Rasul, M. G., Chowdhury, A. A., & Ashwath, N. (2012). Biofuels Production through Biomass Pyrolysis-A Technological Review. Energies Journal, 5(12), 4952–5001. https://doi.org/https://doi.org/10.3390/en5124952

Jambeck, J. R., Geyer, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768–771. https://doi.org/http://doi.org/10.1126/science.1260352

Krisyanti, I. V., & Priliantini, A. (2020). Pengaruh Kampanya #Pantang Plastik terhadap Sikap Ramah Lingkungan (Survei pada Pengikut Instagram @GreenpeaceID). Jurnal Komunika, 9(1), 40–51.

Kumar, S., Panda, A. K., & Singh, R. K. (2011). A Review On Tertiary Recycling Of High-Density Polyethylene To Fuel. Resources, Conservation & Recycling, 55(11), 893–910. https://doi.org/https://doi.org/10.1016/j.resconrec.2011.05.005

Lekpradit, T., & Namkhat, A. (2017). Two-Stage Combustion Burner Using Used Engine Oil as Fuel. KeyEngineering Materials, 751, 442–448. https://doi.org/10.4028/www.scientific.net/KEM.751.442

Nasrun, Kurniawan, E., & Sari, I. (2015). Pengolahan Limbah Kantong Plastik Jenis Kresek Menjadi Bahan Bakar Menggunakan Proses Pirolisis. Energi Elektrik, IV(1), 1–5. Retrieved from https://core.ac.uk/download/pdf/230118101.pdf

Oktora, R., Alwie, H. R., & Utari, S. A. (2019). Inovasi Pengolahan Sampah Plastik Menjadi Bahan Bakar Minyak di Desa Jampang Bogor. In Seminar Nasional Pengabdian Masyarakat LPPM UMJ (pp. 1–6). Jakarta: LPPM UMJ.

Prasetya, H., Rudhiyanto, & Fitriyanto, I. E. (2017). Mesin Pengolah Limbah Sampah Plastik Menjadi Bahan Bakar Alternatif. Media Neliti, 1–5. Retrieved from https://media.neliti.com/media/publications/170300-ID-mesin-pengolah-limbah-sampah-plastik-men.pdf

Pratama, A., Basyirun, B., Atmojo, Y. W., Ramadhan, G. W., & Hidayat, A. R. (2020). Rancang Bangun Kompor (Burner) Berbahan Bakar Oli Bekas. Mekanika: Majalah Ilmiah Mekanika. https://doi.org/10.20961/mekanika.v19i2.42378

Purwaningrum, P. (2016). Upaya Mengurangi Timbulan Sampah Plastik di Lingkungan. Teknik Lingkungan, 8(2), 141–147. Retrieved from https://www.trijurnal.lemlit.trisakti.ac.id/index.php/urbanenvirotech/article/download/1421/1234

Ramanda, S., & Dewiyani, L. (2022). Business Plan Pemanfaatan Sampah Plastik Menjadi Bahan Bakar Minyak Sebagai Implementasi Social Entrepreneurship di Pulau Harapan. Jurnal Integrasi Sistem Industri, 9(1), 13–23. https://doi.org/https://dx.doi.org/10.24853/jisi.9.1.13-23

Riandis, J. A., Setyawati, A. R., & Sanjaya, A. S. (2021). Pengolahan Sampah Plastik Dengan Metode Pirolisis Menjadi Bahan Bakar Minyak. Jurnal Chemurgy, 05(1), 8–14.

Ridhuan, K., Irawan, D., & Inthifawzi, R. (2019). Proses Pembakaran Pirolisis dengan Jenis Biomassa dan Karakteristik Asap Cair yang Dihasilkan. Turbo, 8(1), 69–78.

Ronal, R. (2015). Analisis Dampak Tempat Pembuangan Akhir (TPA) Sampah di Kota Bengkulu Terhadap Lingkungan Sekitar. Bengkulu Mandiri.

Rubiono, G., & Yasi, R. M. (2017). Sosialisasi Manajemen Limbah Oli Bengkel Mobil: Pengabdian Masyarakat di Desa Pesucen Kecamatan Kalipuro Kabupaten Banyuwangi. Jurnal Jati Emas, 1(1), 5–9. Retrieved from http://repository.unibabwi.ac.id/id/eprint/238/1/1.1 Jurnal Jati Emas Ratna.pdf

Sumartono, Ibrahim, H., & Sarjianto. (2018). Uji Karakteristik Bahan Bakar Minyak (BBM) Dari Limbah Plastik. In 9th Industrial Research Workshop and National Seminar (pp. 380–385). Bandung. Retrieved from https://jurnal.polban.ac.id/proceeding/article/view/1126/926

Surono, U. B., & Ismanto. (2016). Pengolahan Sampah Plastik Jenis PP, PET dan PE Menjadi Bahan Bakar Minyak dan Karakteristiknya. Junral Mekanika Dan Sistem Termal, 1(1), 32–37. Retrieved from http://e-journal.janabadra.ac.id/index.php/JMST/article/view/UNTORO

Utami, M. I., & Ningrum, D. E. A. F. (2020). Proses Pengolahan Sampah Plastik di UD Nialdho Plastik Kota Madiun. Indonesian Journal of Conservation, 9(2), 89–95. Retrieved from https://journal.unnes.ac.id/nju/index.php/ijc/article/view/27347/11181

Wajdi, B., Sapiruddin, S., Novianti, B., & Zahara, L. (2020). Pengolahan Sampah Plastik Menjadi Bahan Bakar Minyak (BBM) Dengan Metode Pirolisis Sebagai Energi Alternatif. Kappa Journal, 4(1), 100–112. https://doi.org/10.29408/kpj.v4i1.2156

Wijaya, A., Alfansi, L., & Benardin. (2013). Pengelolaan Sampah Di Kota Bengkulu. Ekonomi Dan Perencanaan Pembangunan, 05(02), 86–95. Retrieved from http://repository.unib.ac.id/7035/1/Pengelolaan.pdf

Yana, S., & Badaruddin. (2017). Pengelolaan Limbah Plastik Sebagai Upaya Pengurangan Pencemaran Lingkungan Melalui Transformasi Yang Memiliki Nilai Tambah Ekonomi. Serambi Engineering, 8(4), 157–164.