



An Investigation of a Hybrid Plasma Gasification System for Various Waste Plastics Thermochemical Degradation in the Fuel Extraction Process

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ABSTRACT

Organic junk contamination is one of the serious environmental concerns throughout today's world. Heavy usage of throwaway plastics devastates nature by obstructing rainwater drainage. From constant exposure to sunlight and warmth, plastics release hazardous gasses into the atmosphere. To reflect the vastly increased amount of various waste plastics, a scaled hybrid plasma gasification reactor is being introduced, which uses an advanced pyrolysis process to break down the plastic waste. The design is simple, transportable, easy to handle, and required very little repair work on long-period usage. Thermochemical investigations are carried out at temperatures ranging from 400 to 600 degrees Celsius, with heating rates ranging from 15 to 22 degrees Celsius per minute, yielding 76-88 percent pyrolysis oil, 10-23 percent syngas, and 4-15 percent chars as besides. It occurs when the molecular architecture of polymers is separated, resulting in the creation of Synthesis gas, which is then condensed into synthesis petroleum fuel. The highest yielding of oil utilizes gas and solid char is determined at 550°C, 600°C, and 450°C respectively, according to the computed pyrolysis kinetic parameter on oil recovery from various waste plastics. The mono-graphic analysis is also used to classify different waste residual char. The model reduces the volume of waste plastic by 89.2%, lowering the detrimental impacts on all living things while simultaneously producing a synthesis of petroleum fuel as a by-product that may be utilized as a replacement or addition to traditional fuel.

INTRODUCTION

Households and hospitals generate a large amount of plastic waste from single-use items. It's no secret that single-use plastic has a harmful effect on the environment. Plastic trash degradation takes between 8 and 1200 years. As a result, it forms a layer over the land surface that acts as a shield to rainfall sinking into the land. Furthermore, it produces hazardous gases into the surroundings as a result of constant solar radiation and heat, which causes health problems for living creatures so it is also partially accountable for environmental warming (Dutta & Paul 2019). In India, around 2,73,84,000 kg of plastic waste is generated every day (Manuja et al. 2020). Today, plastic waste management has become a major concern in developed countries (Gupta et al. 2015). It has been reported that by 2022, India's annual plastic consumption will increase from 15 million tonnes to 24 million tonnes annually. As a result of synthetic polymers made from petroleum as raw material (Salandra 2018), India's plastic manufacturing industries have grown over the past seven degenerations. Polyethylene Terephthalate, Polyethylene, High-Density Polyethylene, Acrylonitrile butadiene styrene, Low-Density Polyethylene, Polyvinyl Chloride, Polypropylene, Polystyrene, polyamide, and

polybutylene terephthalate are some of the most important synthetic plastic polymer products. These products generate 52% of the plastic waste that ends up in rivers and on land. As a result, India's single-use plastic waste management is a major concern. For hospital waste, however, there are no international standards for the classification of the waste. World Health Organization (WHO) estimates that 20 percent of plastic hospital wastes are potentially unsafe materials that may contain a transferrable, poisonous, or irradiated element (Fang et al 2020). From the perceptive of ecological preservation and preventing infection, it has innumerable implications to improve the appropriate and safe treatment and disposal of medical waste plastics.

The thermolysis process also knowns as gasification or pyrolysis, is one of the most important chemical recycling technologies for waste plastic. In this process splitting frequency involve a temperature at which plastic molecules vibrates is directly proportional to the temperature of the molecules and a high temperature and restriction of oxygen cause material breakdown, which might result in syngas, liquids, or wax as the ultimate product, depending on the conditions of pyrolysis (Rahimi & García 2017). For the recycling of plastic waste, experts have devised and tested a variety of methods. Mechanical recycling techniques are

ideal, but plastic trash must be homogeneous and uncontaminated during the recycling process for it to be successful (Punčochář et al. 2012).

Thermolysis or gasification is an alternative to burning treatment that has been extensively investigated (Pinto et al. 2002, Sekiguchi & Orimo 2004), with several patents already in place. Even now, thermal plasma technology is a well-known technology, and its research is ongoing. Metallurgical processing, synthesizing, and coating processes are all well-known applications for this technique (Sekiguchi and Orimo 2004). In the plasma process, an electron breaks the molecules as travel through a high electrical field, which causes dissociation, ionization, and, excitation of the originating material. This creates exciting molecular species, ionic and active radical forms that trigger the chemical plasma reaction (Tendero et al. 2006, Fridman et al. 2008).

Considering safety concerns, the most important use of thermal plasma waste treatment is the obliteration of hazardous materials (Pun ochá et al. 2012, Samal 2017), instead of conventional recycling or mechanical recycling techniques. Compared to the standard pyrolysis process, thermal plasma pyrolysis provides many advantages. As a result of a high amount of energy for the thermolysis process, it produces a high temperature. As a result of the rapid heating of the material, certain significant reactions occur that do not emerge in the traditional pyrolysis approach (Heberlein & Murphy 2008). As a result of the higher temperature, it generates more syngas (a volatile substance including CO, H₂, CH₄, C₂H₂, and other hydrocarbons) with a lower tar content, which may be utilized immediately to drive gas turbine power plants or

stored for use in other applications. Organic carbon solids waste may be transformed into valuable gaseous fuel by using the thermal plasma method, as demonstrated in previous bench-scale studies (Mumbach et al. 2019).

The research investigation focused on a hybrid plasma gasification reactor system for waste plastic as organic material. The main areas that have been presented for studies are gathered detailed details on the characteristics of waste plastic materials in the pyrolysis process. On hybrid plasma, pyrolysis to evaluate the pyrolysis oil recovery rate and kinematics parameters with varied temperature variances in different waste plastic. On conduct comparative investigations of residual weight analysis using a variety of temperature ranges from the pyrolysis process. And investigate waste char slag from various organic carbon solids waste during hybrid plasma pyrolysis.

MATERIALS AND METHODS

Setup and Procedure

Experimental setup equipped with a hybrid heating technology on the combination of the bottom electric heater with advanced cylindrical plasma heater for batch gasification reactor. The reactor has a volumetric capacity of eight kg per hour of organic waste materials. Fig. 1 shows the schematic diagram of a hybrid plasma gasification reactor. The hybrid plasma gasification reactor vertical type, heating furnace height of 0.80 m, and diameter of 0.25 m. A screw feeder-powered motor feeds small bits of organic waste from top feeding storage raw material storage, and then into the

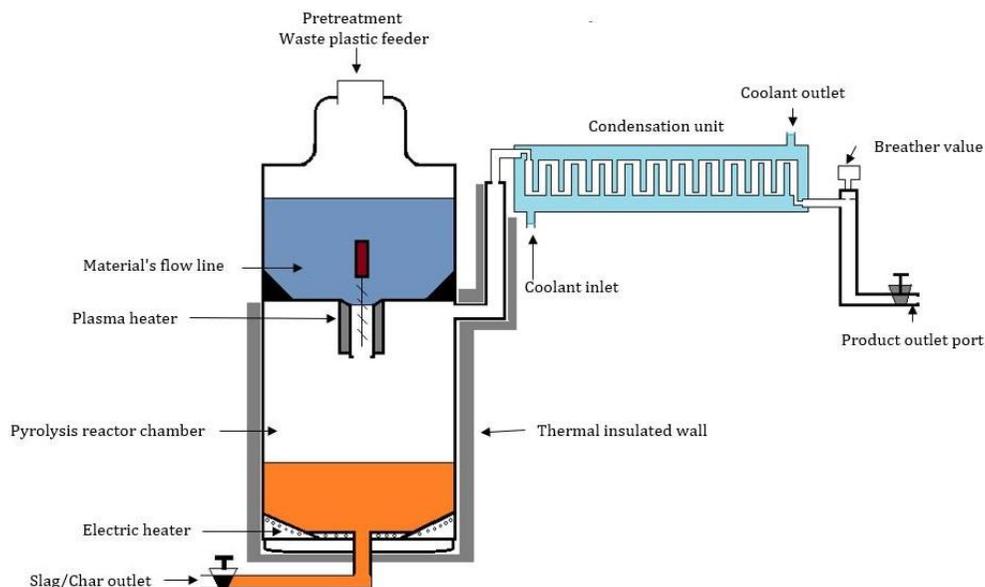


Fig. 1: Schematic diagram of hybrid plasma gasification reactor.

plasma gasification unit. An optional inert (nitrogen) gas port for supply to the reactor chamber with a control pressure valve for the removal of oxygen for the pyrolysis method. The inner part of the plasma heater is revealed in Fig. 2. The plasma heater's surface is composed of stainless steel and has two layers. To prevent heat loss, both sides of the plasma heater are coated with refractory clay. Fig. 2 shows a graphite electrode set at an equal distance between stainless steel half-circular rings anodes fixed within the plasma heater in such a way that voltage from the power source can generate high temperature at the feeder point without damaging the heater pipe in the reactor. A molten liquid sterling motor and a sterling motion unit are employed at the bottom of the furnace, coupled with an 800 W modified electric heater attached at the bottom of the reactor, due to the high viscosity of the liquid state.

Waste from the reactor chamber is collected via a waste slag/char outflow. The pressure sensor is used to determine the stability of the reactor, while the temperature sensor is a K-type thermocouple. For the condensation process, pressurized syn-gases are fed into the condenser. The condensation of synthesis gas takes place in a liquid heat exchanger. Fig. 1 depicts the coolant inlets and outflow port. Subsequently, it is stored in the final collector container through the product outlet valve. The temperature profile up to 600°C was used to investigate the temperature distribution in the reactor chamber during pyrolysis without raw material and a thermal plasma system. Fig. 3 shows a temperature distribution profile. The temperature was measured in an empty reactor chamber at a 15°C time interval. Fig. 4 shows the placement of the thermocouple and it's used for the measurement of temperature during the experiment.

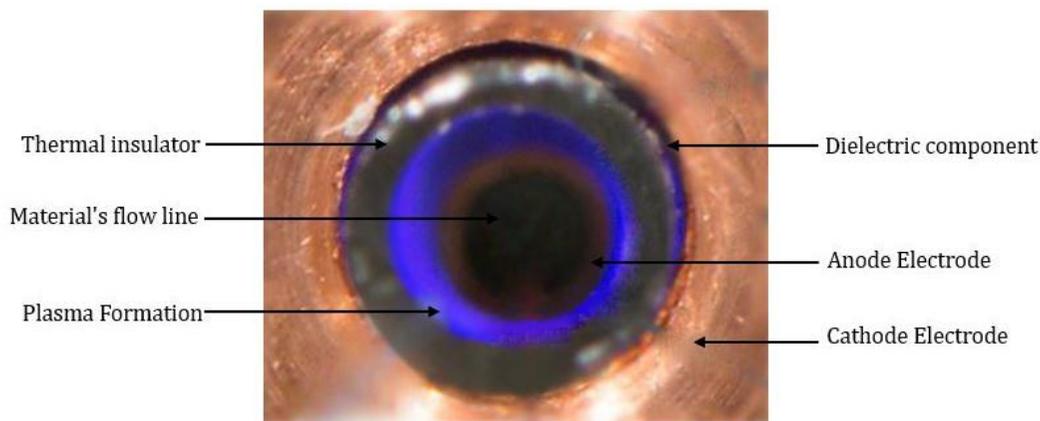


Fig. 2: Inside view of plasma heater.

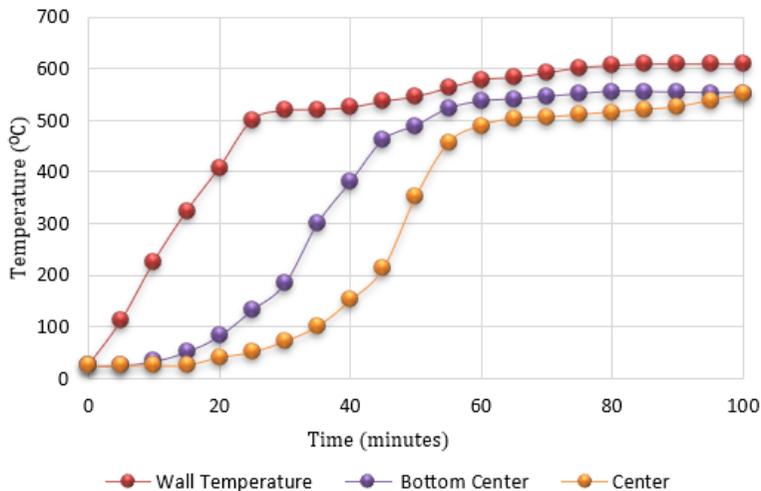


Fig. 3: Empty chamber temperature distribution profile.

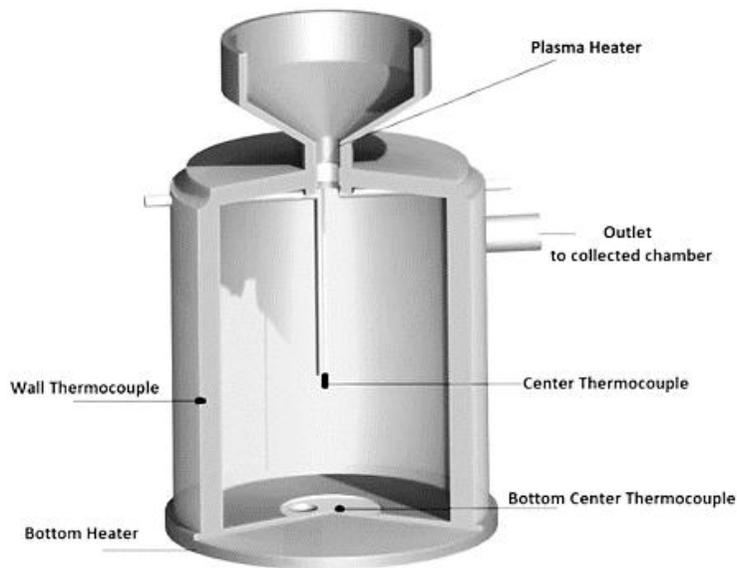


Fig. 4: Placement of thermocouple in the pyrolysis chamber.



(a)



(b)

Fig. 5: (a) Pyrolysis oil collector unit (b) View of reactor setup.

Fig. 5 depicts the entire bench-scale 8 kg hybrid plasma gasification reactor setup with filtered syngas and a pyrolysis oil collector. Completely operational electric operated apparatus featuring 650°C thermally brake temperatures, single phase 230 V AC electrical heater, and a plasma heater system. A cylinder container with a tapering bottom half shell makes up a plasma heater. It is made up of four squared graphite electrodes that serve as the cathode in an electrical system with a high current DC source transformer.

Materials

The organic garbage (waste plastic) was obtained from the

Kalinga Institute of Medical Science (KIMS) and the municipal corporation of Bhubaneswar, Odisha. Selected, it's been divided into seven separate sterilized and dried waste plastic grads. For the aim of the experiment, each waste sample plastic was obtained in an identical mass ratio. Various forms of plastic were gathered for pyrolysis/gasification are shown in Fig. 6. Table 1 shows several types of waste plastic, as well as their generic kind and plastic-type indication. Individual types of plastic trash may be seen in the experiment. Following classification, the items are chopped into small pieces ranging from 10 to 40 millimeters in length using a cutter machine.

Table 1: List of collected waste plastic Materials (Punčochář et al. 2012, Deng et al. 2008, Lin et al. 2010, Klemeš et al. 2020, Qin et al. 2018).

S No.	Mark	Code	Type of plastics	Waste plastic materials
1	PET		Polyethylene Terephthalate	Saline bottles, juice containers, Mineral water bottles, soft drink bottles, vacutainers, photographic film
2	HDPE		High-density polyethylene	one-off dustbin pouch, milk pouch, Packaging sheets, or pouch
3	PVC		Polyvinyl Chloride	Tube for blood and Urine, Sample collector bottle
4	LDPE		Low-density polyethylene	Sample collector small bag, Disposable gloves, trash bag
5	PP		Polypropylene	Disposable masks-shoe-covers & caps, cytotoxic drugs packaged, dustpans worn one, Syringes body and plunger
6	PS		Polystyrene	ET Tube, Suction's tube & bags, Plastic cover for light handles,
7	PE, PA, ABS, PBT		Polyethylene, polyamide, acrylonitrile butadiene styrene, polybutylene terephthalate	Plastic Bag Warmer Patients ID Bands, Gloves, Intravenous tubes, and sets,



Fig. 6: Various forms of gathered waste plastic for gasification.

RESULTS AND DISCUSSION

Oil Recovery Rate with Calculated Pyrolysis Kinetic Parameter

According to an oil recovery investigation, increasing reactor temperatures reduces oil recovery time. As a consequence

of the shorter time that volatiles spends in the reaction chamber, carbon bonding separation with high molecular heaviness composition occurs, increasing the concentration of the pyrolysis oil generated. The kinetic parameters were derived using the Arrhenius plot technique during every oil recovery process. Fig. 7 shows the oil recovery rate from

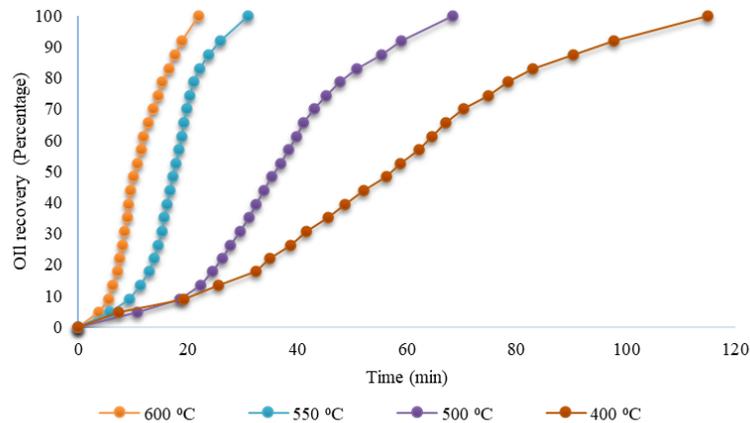


Fig. 7: Oil recovery rate for PET at a heating rate of nearly 18°C/minutes.

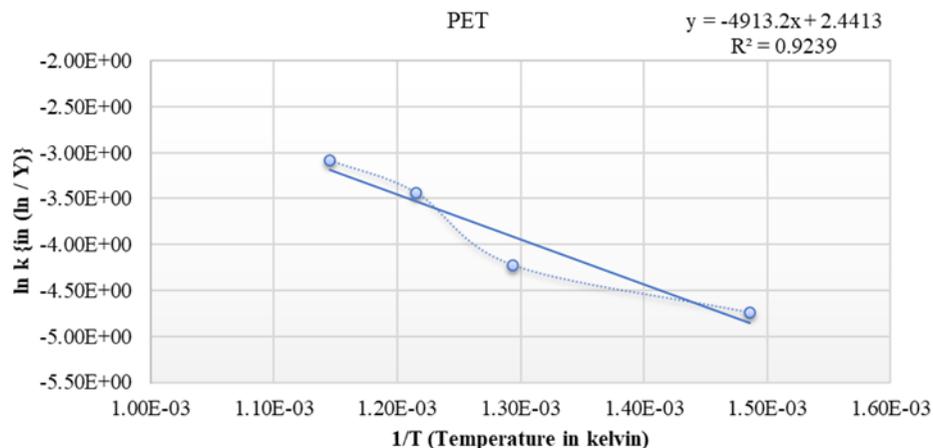


Fig. 8: Graphical calculation of activation energy for PET.

PET it takes 22, 31, 69, and 114.8 min at 600, 550, 500, and 400°C respectively. Fig. 8 shows a graphical calculation of activation energy based on kinetic parameters for PET.

Fig. 9 shows the oil recovery rate from HDPE takes 26, 31, 69.8, and 115.5 min at 600, 550, 500, and 400°C respectively. However, the pattern of oil recovery percentage increase with time for PET and HDPE. Fig. 10 shows a graphical calculation of activation energy based on kinetic parameters for HDPE.

Fig. 11 shows the oil recovery rate from PVC takes 38, 43, 84, and 132 min at 600, 550, 500, and 400°C respectively. The pattern of oil recovery increment from PVC concerning time is similar up to 70% of oil recovery as PET, HDPE, and LDPE showed, but in this case, the oil recovery rate decreases after 70% oil recovery. Fig. 12 shows a graphical calculation of activation energy based on kinetic parameters for LDPE.

Fig. 13 shows the oil recovery rate from LDPE takes 23, 34, 72, and 117 min at 600, 550, 500, and 400°C respectively. However, the pattern of oil recovery percentage increase with time for PET and HDPE. Fig. 14 shows a graphical computation of activation energy based on kinetic parameters for LDPE.

Fig. 15 shows the oil recovery rate from PP takes 24, 33, 64, and 113 min at 600, 550, 500, and 400°C respectively. The pattern of oil recovery from PP is similar to 80% oil recovery like that of PET, HDPE, and LDPE, and beyond that, the trend does not match. Fig. 16 shows a graphical calculation of activation energy based on kinetic parameters for PP.

Fig. 17 shows the oil recovery rate from PS takes 19, 27, 44, and 92 min at 600, 550, 500, and 400°C respectively. The pattern of oil recovery is similar to a nearly straight line till 80% oil recovery but the oil recovery rate decreases

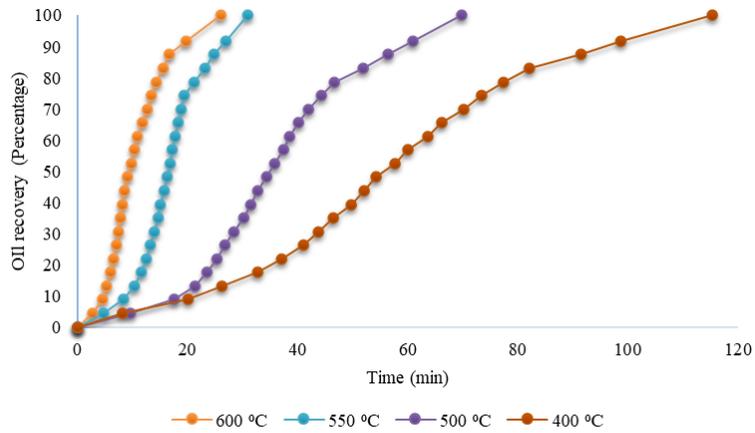


Fig. 9: Oil recovery rate for HDPE at a heating rate of nearly 18°C/minutes.

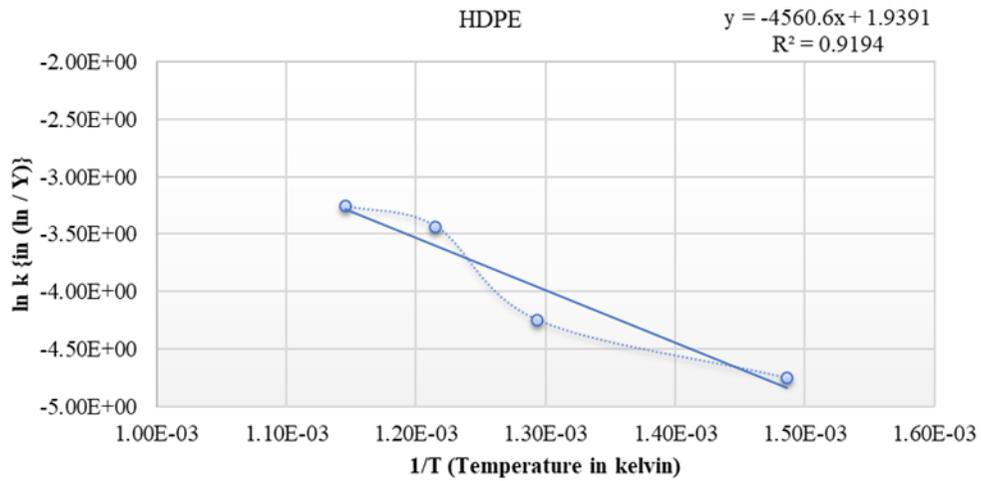


Fig. 10: Graphical calculation of activation energy for HDPE.

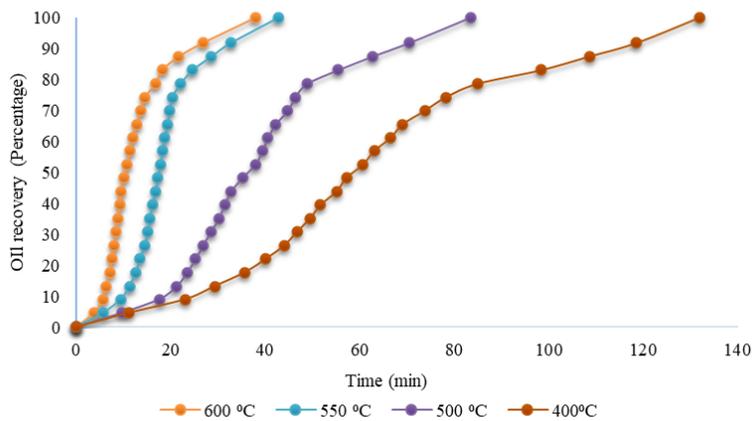


Fig. 11: Oil recovery rate for PVC at a heating rate of nearly 18°C/minutes.

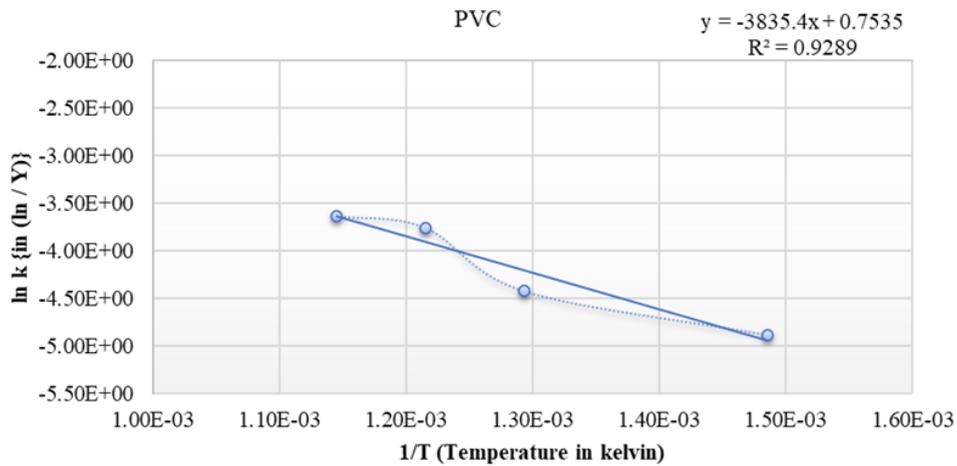


Fig. 12: Graphical calculation of activation energy for PVC.

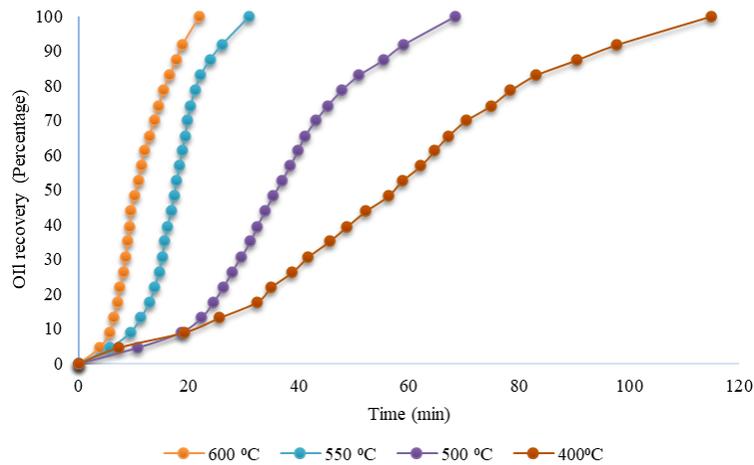


Fig. 13: Oil recovery rate for LDPE at a heating rate of nearly 18°C/minutes.

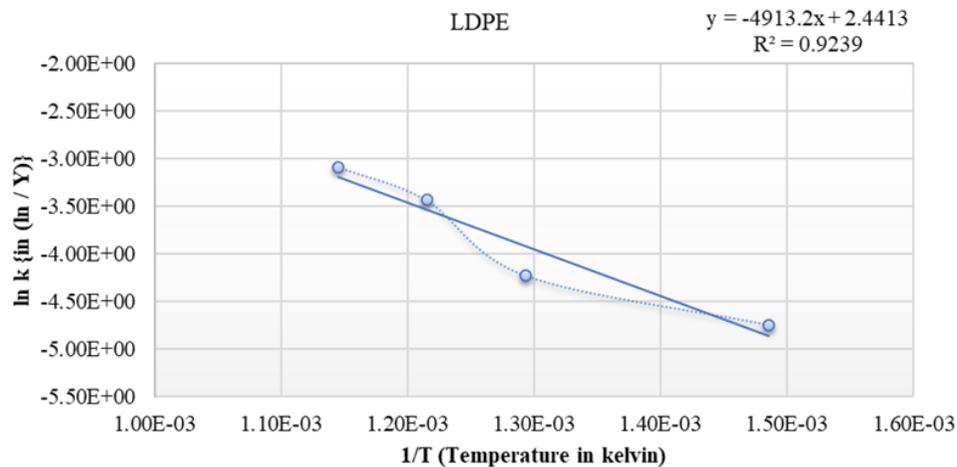


Fig. 14: Graphical calculation of activation energy for LDPE.

afterward. Fig. 18 shows a graphical calculation of activation energy based on kinetic parameters for PS.

Fig. 19 shows the oil recovery rate from a mixture of various plastics, where the mixture is prepared by taking the equal weight of each kind of plastic. It takes 28, 37, 82, and 135 min at 600, 550, 500, and 400°C respectively. The pattern of oil recovery is similar to a nearly straight line till 80% oil recovery but the oil recovery rate decreases afterward. Fig. 20 shows a graphical calculation of activation energy for mixed plastics based on kinetic parameters.

The oil recovery pattern is comparable to all prior tests, although the results for 550°C and 600°C are virtually identical to earlier trials. In all cases, oil production began when the temperature of the reactor core reached 380°C, with

sluggish oil recapturing in the first stage and increasing when the temperature of the reactor was above 450°C. Oil recovery was extremely quick at high operating temperatures. At lower temperatures, polypropylene and polyethylene terephthalate break down, followed by hydrogen abstraction and random scission. In the early stages, degradation is caused by polystyrene end chain scission followed by scission, resulting in increased gas production such as hydrogen and methane. Increases in process temperature cause deterioration, which is followed by scission formation of larger quantities of extended chain hydrocarbon, resulting in higher liquid yield in all cases.

The Arrhenius plot is generated and shown in the above figures. Each plot in the figures shows S-shape curves which

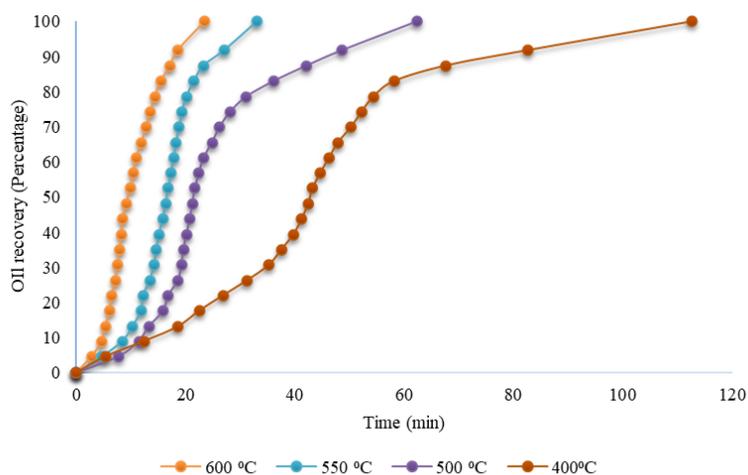


Fig. 15: Oil recovery rate for PP at a heating rate of nearly 18°C/minutes.

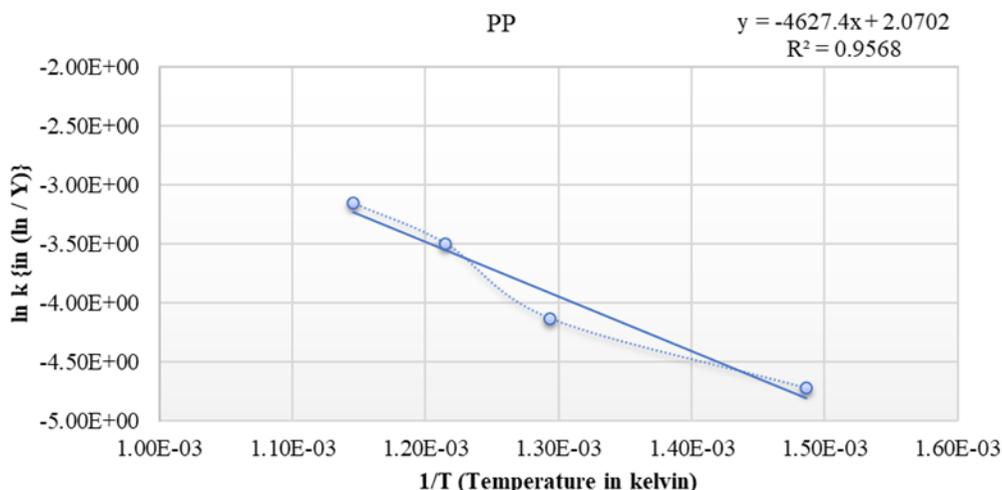


Fig. 16: Graphical calculation of activation energy for PP.

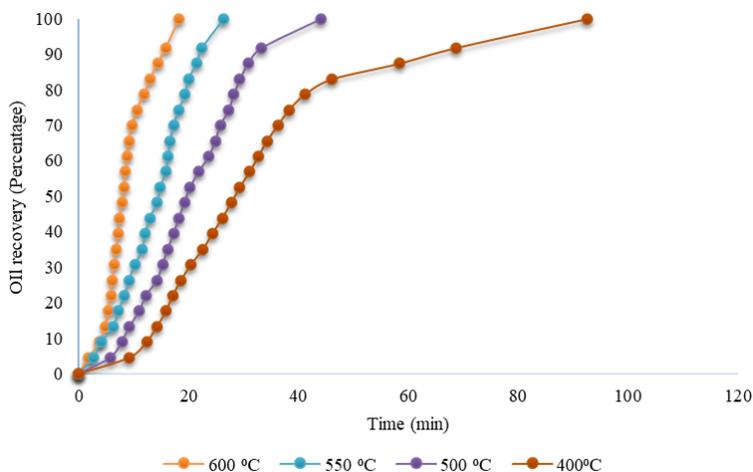


Fig. 17: Oil recovery rate for PS at a heating rate of nearly 18°C/minutes.

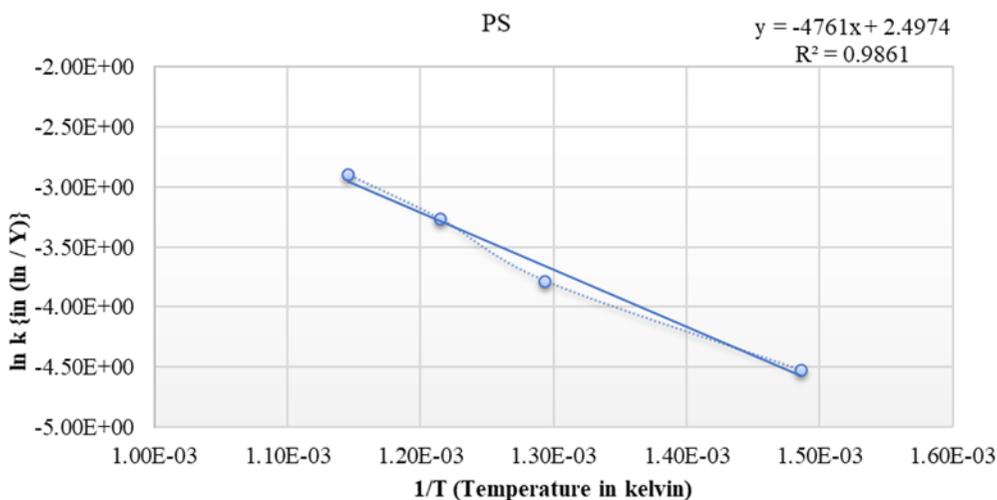


Fig. 18: Graphical calculation of activation energy for PS.

means that the kinetics of the reaction follows the nucleation and grain growth model and Johnson and Mehl (Sarkar & Ray 1990) equation: $\ln[-\ln(1-\alpha)] = n \ln(k') + n$. The calculated value of activation energy for polyethylene terephthalate (PET) is 40.84 kJ.mole⁻¹ and exponential factor 11.488/second; similarly, high-density polyethylene (HDPE) is 37.91 kJ.mole⁻¹, exponential factor 6.896/second; Low-density polyethylene (LDPE) is 40.84 kJ.mole⁻¹, exponential factor 11.487/second; Polyvinyl chloride (PVC) is 31.88 kJ.mole⁻¹, exponential factor 2.124/second; Polypropylene (PP) is 38.47 kJ.mole⁻¹ exponential factor 7.926/second; Polystyrene (PS) 39.58 kJ.mole⁻¹ exponential factor 12.150/second; and Mixed 39.51 kJ.mole⁻¹ exponential factor 7.784/second.

Wu et al. (1993) recorded lower values of 233-326 kJ.mol⁻¹ for HDPE, 194-206 kJ.mol⁻¹ for LDPE, 184-265 kJ.mol⁻¹ for PP, and 172 kJ.mol⁻¹ for PS. Again, Sorum et

al. (2001) identified commercial-grade activation energy as 445.1 kJ.mol⁻¹ for HDPE, 340.8 kJ.mol⁻¹ for LDPE, 336.7 kJ.mol⁻¹ for PP, and 311.5 kJ.mol⁻¹ for PS respectively. Similarly, Diaz-Silvarrey and Phan (2016) found activation energy waste as HDPE 375.59 kJ.mol⁻¹, LDPE 267.61 kJ.mol⁻¹, PP 261.22 kJ.mol⁻¹, PS 192.61 kJ.mol⁻¹, and PET 197.61 kJ.mol⁻¹ respectively.”

The activation energy (40.89 kJ.mol⁻¹) is far smaller compared to that above. This demonstrates the benefit of the plasma reaction which reduces energy activation (Sabat 2014, Rajput et al. 2016). The semi-batch pyrolysis thermal reactor is more impactful in the terms of disposal of waste plastic.

Residual Weight Analysis

The weight fractions of all plastic samples vary with temperature in this investigation. It has been determined that LDPE

and PET have distinct weight fraction curve patterns. Fig. 21 also illustrates a distinct pattern of the curve after 52°C and 500°C at a rate of 18°C for PS and PP, respectively. This indicated the normal thermal degradation process during pyrolysis (Mumbach et al. 2019).

Characteristics

Pyrolysis oil

During the investigation, we obtained the product as pyrolysis oil from various waste plastic elements. Fig. 22 depicts the collection of pyrolysis oil in containers and waste plastic samples with oil extraction. Fig. 23 depicts the collection of a waste plastic sample with oil extraction.

In terms of pyrolysis oil’s characteristics, we tested all collected samples for density at 28 °C using the ISO-1183

method, kinematic viscosity at 23°C using the ISO-3104 method, flash point using the ISO 2719 standard method, fire point using the ISO 2592 method, calorific value using a bomb calorimeter, pour point using the ISO 3016 testing method, and ash content using the ISO 3451 testing method. Table 2 shows lists all of the physical characteristics of waste plastic pyrolysis oil with petroleum diesel and petrol. Table 2, showing the comparison of (Renewable diesel and petrol) parameter properties of all plastic pyrolysis oil, indicated that it can be a substitute as a furnace oil for the power plant or as an industrial diesel. Mixed pyrolysis oil can be blended with diesel/ petrol and used for automobile cars.

Waste Char

After the examination, we got char as a waste of the plastic pyrolysis of the different plastic waste materials. Under the

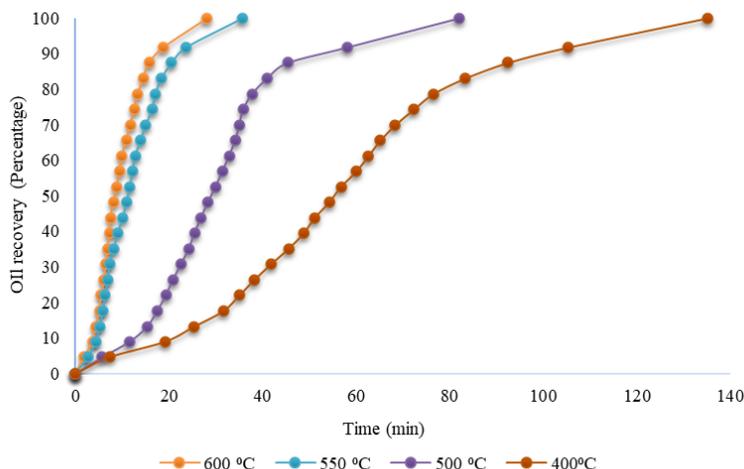


Fig. 19: Oil recovery rate for mixed plastics at a heating rate of nearly 18 °C/minutes.

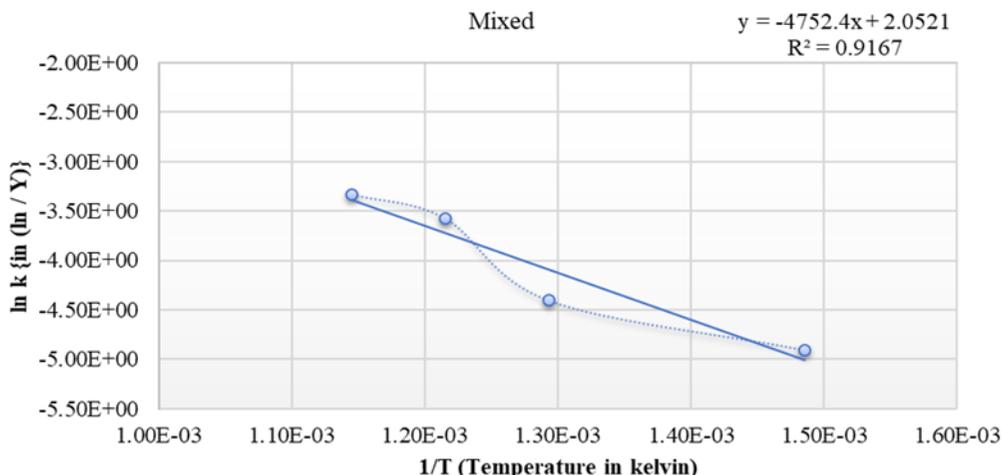


Fig. 20: Graphical calculation of activation energy for mixed plastics.

micrographic observation of the individual plastic material of char, SEM images of plastic char are shown in Fig. 24 (a), (b), (c), (d), (e), and (f)

Polyethylene Terephthalate (a) char is being seen with a 15X magnification at 1200 μm and 150X magnification at 600 μm respectively. We observed that some carbon black sub-

stance was present in char. It indicates the presence of printed paint and marks on PET-type plastic waste material that has not completely decomposed during thermal pyrolysis.

Low-density polyethylene (b) char is being seen with a 15X magnification at 1200 μm and 150X magnification at 600 μm respectively. We observed the absence of carbon

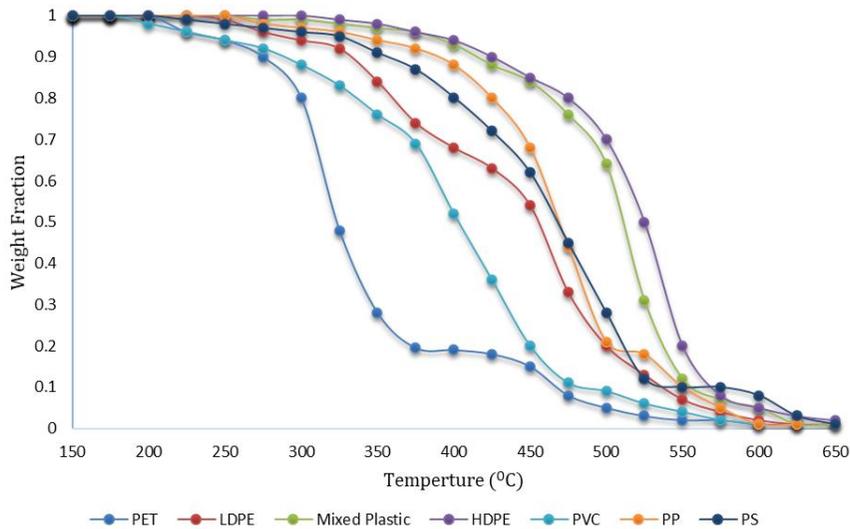


Fig. 21: Comparative residual weight analysis with the temperature at a rate of 18 °C for specific and mixed plastic waste.



Fig. 22: Oil extraction by thermal plasma pyrolysis of Hospital plastic waste materials.

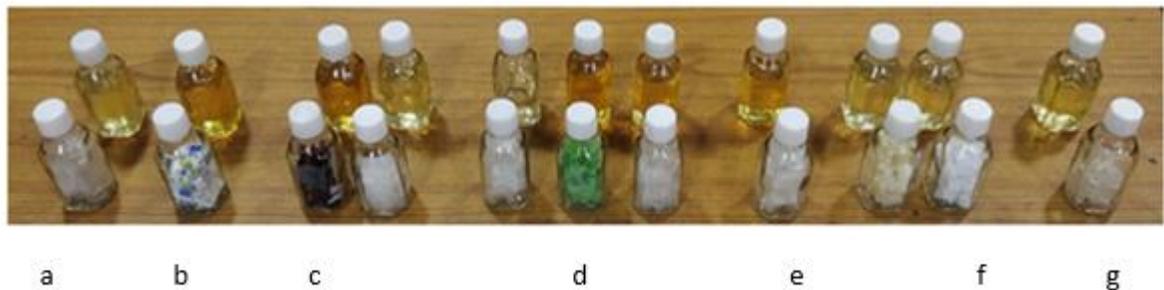


Fig. 23: Waste plastic sample with oil extraction by thermal plasma pyrolysis (a)PET, (b)LDPE, (c)HDPE, (d)PP, (e)PS, (F)PVC, (g) ABS, PA, PBT.

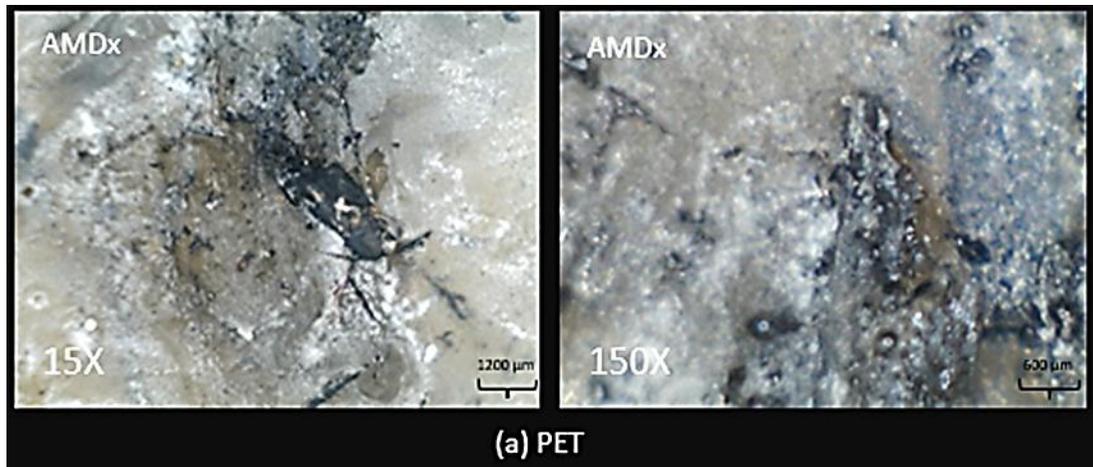


Fig. 24: (a) Microscopic view of Polyethylene Terephthalate waste char.

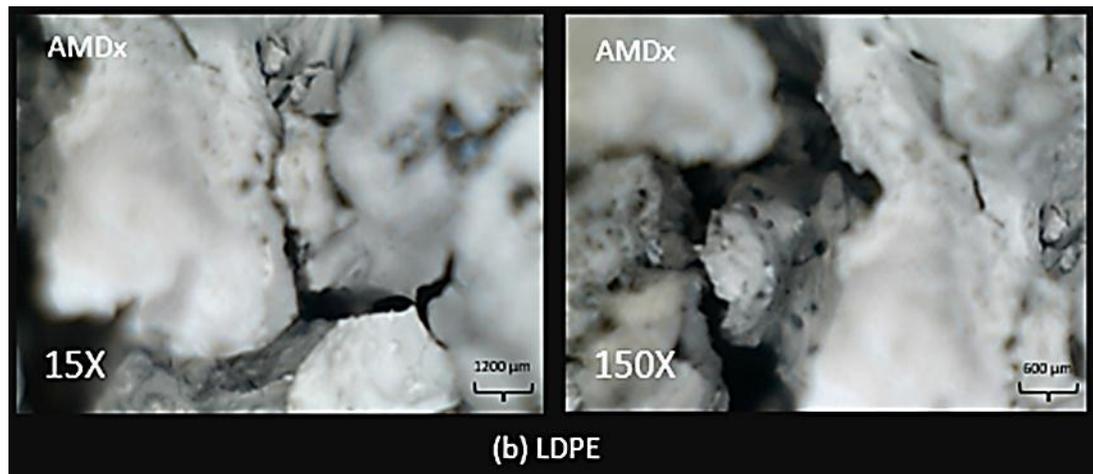


Fig. 24: (b) Microscopic view of Low-density polyethylene waste char.

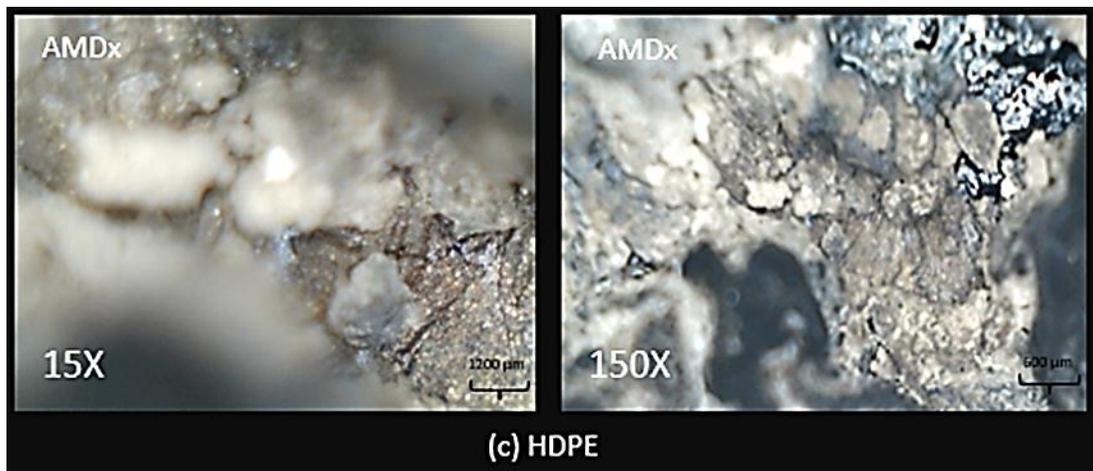


Fig. 24: (c) Microscopic view of High-density polyethylene waste char.

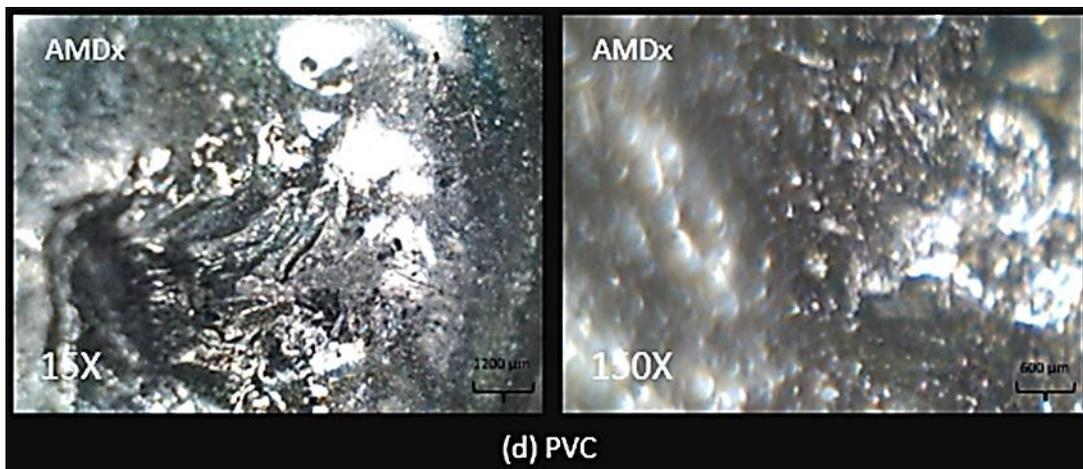


Fig. 24: (d) Microscopic view of polyvinyl chloride waste char.

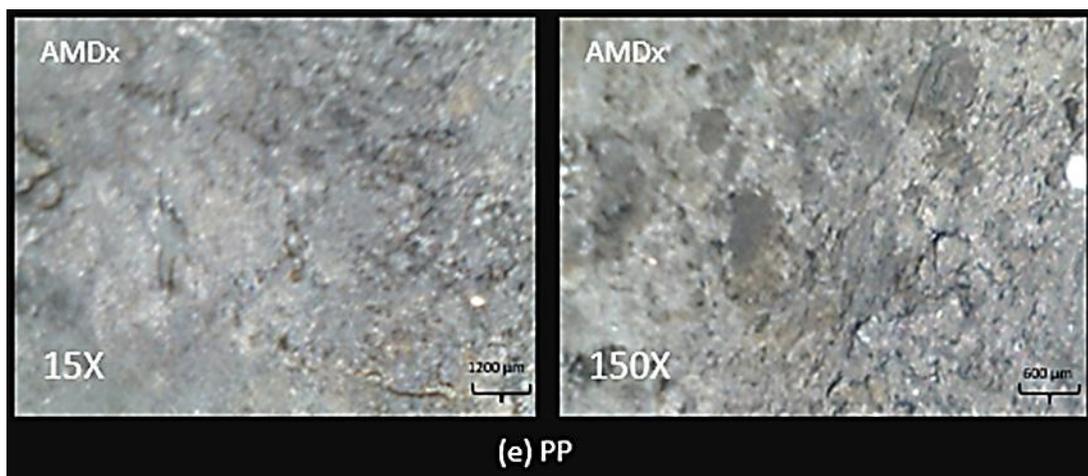


Fig. 24: (e) Microscopic view of polypropylene waste char.

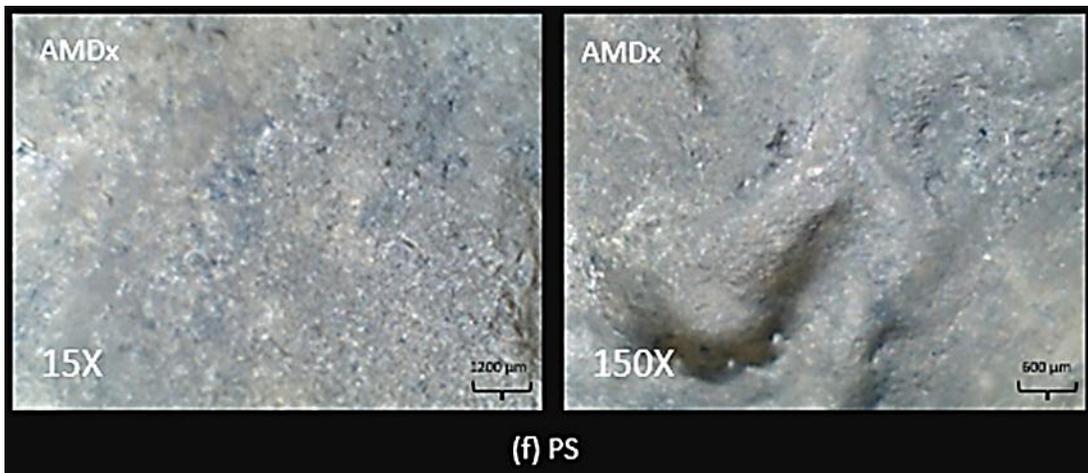


Fig. 24: (f) Microscopic view of polystyrene waste char.

Table 2: The physical characteristics of various plastic pyrolysis oils.

Physical properties	Pyrolysis Oil from different types of plastic waste							Petroleum	
	PET	HDPE	LDPE	PVC	PP	PS	Mixed	Diesel	Petrol
Density @ 26°C [g.cm ⁻³]	0.88	0.87	0.76	0.82	0.84	0.83	0.91	0.84-0.86	0.82-0.86
Kinematic viscosity [mm ² .s ⁻¹]	3.92	4.86	4.97	5.82	4.16	2.85	6.02	3.04-4.83	1.12-3.27
Flash point [C°]	28.2	47.8	40.0	39.0	30	27.1	32	52-94	42-108
Calorific value [MJ.kg ⁻¹]	27.8	41.5	39.8	21.6	40.8	43.0	40.01	35.7-42.7	34.2-46.48
Pour point (C°)	-18	-5	-9	4	-9	-67	5	0.0 - 55	0.0-50
Ash content [wt %]	0.002	0.04	0.02	0.04	0.002	0.006	0.01	-	-

black substance present in char. It indicates the material has completely decomposed during the pyrolysis process.

High-density polyethylene (c) char is being seen with a 15X magnification at 1200 µm and 150X magnification at 600 µm respectively. We observed about 3.68% - 3.97% carbon black substance with ash and large bonding molecular particles present in char. It is quite low. It means that HDPE materials decomposed during the pyrolysis process.

Polyvinyl Chloride (d) char is being seen with a 15X magnification at 1200 µm and 150X magnification at 600 µm respectively. We observed about 28.86% - 30.28% carbon black substance with ash and compact bonding molecular particles present in char. It indicates the presence of additive added into PVC that is commonly composed of the inorganic residual compound for the improvement of properties of PVC.

Polypropylene (e) char is being seen with a 15X magnification at 1200 µm and 150X magnification at 600 µm respectively. We observed a random uniform structure of molecular bonding present in char. It indicates that the material degraded during the pyrolysis operation.

Polystyrene (f) char is being seen with a 15X magnification at 1200 µm and 150X magnification at 600 µm respectively. We observed that char has a consistent structure of molecular bonding. It indicates that the material was degraded during the pyrolysis operation.

CONCLUSION

Hybrid plasma pyrolysis is most effective in the terms of activation energy i.e., nearly about 40.89 kJ.mol⁻¹ generating yielding of 76-88% pyrolysis oil, 10-23% syngas, and 4-15% chars as a product. The calorific value of pyrolysis oil is about 39-41 MJ per kg, indicating that it has the highest potential energy value as an alternative for petroleum-based diesel and petrol. The current investigations show that there are a plethora of options for developing hybrid plasma gasification technologies that apply to organic waste plastic materials disposal treatment with material and energy recapture.

REFERENCES

- Deng, N., Zhang, Y. F. and Wang, Y. 2008. Thermogravimetric analysis and kinetic study on pyrolysis of representative medical waste composition. *Waste Management*, 28(9), 1572-1580.
- Diaz-Silvarrey, L. and Phan, A. 2016. 'Kinetic study of municipal plastic waste', *International Journal of Hydrogen Energy* 41(37), 16352-16364.
- Dutta, M. and Paul, G. 2019. Gallic acid protects rat liver mitochondria ex vivo from bisphenol A induced oxidative stress mediated damages. *Toxicology reports*, 6, 578-589.
- Fang, S., Jiang, L., Li, P., Bai, J. and Chang, C. 2020. Study on pyrolysis products characteristics of medical waste and fractional condensation of the pyrolysis oil. *Energy*, 195, 116969.
- Fridman, G., Friedman, G., Gutsol, A., Shekhter, A. B., Vasilets, V. N. and Fridman, A. 2008. Applied plasma medicine. *Plasma processes and polymers*, 5(6), 503-533.
- Gupta, N., Yadav, K. K. and Kumar, V. 2015. A review on current status of municipal solid waste management in India. *Journal of environmental sciences*, 37, 206-217.
- Heberlein, J. and Murphy, A. B. 2008. Thermal plasma waste treatment. *Journal of Physics D: Applied Physics*, 41(5), 053001.
- Klemeš, J. J., Van Fan, Y., Tan, R. R. and Jiang, P. 2020. Minimising the present and future plastic waste, energy and environmental footprints related to COVID-19. *Renewable and Sustainable Energy Reviews*, 127, 109883.
- Lin, H. T., Huang, M. S., Luo, J. W., Lin, L. H., Lee, C. M. and Ou, K. L. 2010. Hydrocarbon fuels produced by catalytic pyrolysis of hospital plastic wastes in a fluidizing cracking process. *Fuel Processing Technology*, 91(11), 1355-1363.
- Manuja, S., Pandey, S. and Bhatia, A. 2020. Assessing Management of Plastic Straws Attached with used Beverage Cartons-A Case Study of 3 Metropolitan Cities of India. (IJERT) Vol. 9 (6):601-606p.
- Mumbach, G. D., Alves, J. L. F., Da Silva, J. C. G., De Sena, R. F., Marangoni, C., Machado, R. A. F. and Bolzan, A. 2019. Thermal investigation of plastic solid waste pyrolysis via the deconvolution technique using the asymmetric double sigmoidal function: Determination of the kinetic triplet, thermodynamic parameters, thermal lifetime and pyrolytic oil composition for clean energy recovery. *Energy Conversion and Management*, 200, 112031.
- Pinto, F., Franco, C., André, R. N., Miranda, M., Gulyurtlu, I. and Cabrita, I. 2002. Co-gasification study of biomass mixed with plastic wastes. *Fuel*, 81(3), 291-297.
- Pun ochá, M., Ruj, B. and Chatterj, P. K. 2012. Development of process for disposal of plastic waste using plasma pyrolysis technology and option for energy recovery. *Procedia Engineering*, 42, 420-430.
- Qin, L., Han, J., Zhao, B., Wang, Y., Chen, W. and Xing, F. 2018. Thermal degradation of medical plastic waste by in-situ FTIR, TG-MS and TG-GC/MS coupled analyses. *Journal of Analytical and Applied Pyrolysis*, 136, 132-145.

- Rahimi, A. and García, J. M. 2017. Chemical recycling of waste plastics for new materials production. *Nature Reviews Chemistry*, 1(6), 1-11.
- Rajput, P., Bhoi, B., Paramguru, R. K. and Mishra, B. K. 2016. Effect of plasma state and alloying addition on reduction of Fe₂O₃ by a low-temperature hydrogen plasma. *High Temperature Material Processes: An International Quarterly of High-Technology Plasma Processes*, 20(4).
- Sabat, K.C. 2014. Reduction of oxide minerals by hydrogen plasma: an overview. *Plasma Chemistry and Plasma Processing* 34.1 and 1-23.
- Salandra, R. 2018. Knowledge dissemination in clinical trials: exploring influences of institutional support and type of innovation on selective reporting. *Research Policy*, 47(7), 1215-1228.
- Samal, S. 2017. Thermal plasma technology: The prospective future in material processing. *Journal of cleaner production*, 142, 3131-3150.
- Sarkar, S. B. and Ray, H. S. 1990. Analysis of kinetic data by Johnson-Mehl equation. *Journal of thermal analysis*, 36(1), 231-242.
- Sekiguchi, H. and Orimo, T. 2004. Gasification of polyethylene using steam plasma generated by microwave discharge. *Thin Solid Films*, 457(1), 44-47.
- Sorum, L., Gronli, M. and Hustad, J. 2001. Pyrolysis characteristics and kinetics of municipal solid wastes, *Fuel* 80, 1217-1227.
- Tendero, C., Tixier, C., Tristant, P., Desmaison, J. and Leprince, P. 2006. Atmospheric pressure plasmas: A review, *Spectrochimica Acta Part B: Atomic Spectroscopy* 61(1), 2-30.
- Wu, C., Chang, C., Hor, J., Shih, S., Chen, L. and Chang, F. 1993. On the thermal treatment of plastic mixtures of MSW: Pyrolysis kinetics, *Waste Management* 13(3), 221-235.