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# Pyrolytic Liquid Fuel – An Alternative for Producing Electrical Energy in Mexico

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**ABSTRACT**

Millions of tons of urban solid waste are discarded yearly in Mexico. The rapid population growth, urbanization, and social development, together with a more significant number of inhabitants, resulted in a massive amount of municipal solid waste (MSW) that is increasing yearly. Most of these end up in landfills without being used for energy, causing severe social and environmental problems. Municipal solid waste (MSW) is the most significant main waste stream (representing 9.21% of the waste that can be used), including plastic bottles, food dishes, cans, bags, and containers. The recycling and sustainable disposal of plastic waste is a significant activity with a high rate of complexity due to various effects that occur during its processes, such as obstructions in mechanisms and pipes, prolonged degradation and biodegradation rates, and the presence of additives, and highly toxic dyes. Pyrolysis is one of the promising technologies for converting waste into sound energy capable of being used in various applications such as power generation, transportation fuel, and multiple thermal purposes. According to the Ministry of Energy (SENER), Mexico has an installed generation capacity of 86,034 MW, of which almost 65% is based on fossil-based technologies.

**Keywords:** pyrolytic liquid, power generation, municipal solid wastes, greenhouses.

## INTRODUCTION

According to the Secretary of the Environment (Naturales secretería de Medio Ambiente y Recursos, 2020), plastic waste is solid waste generated in homes or the industrial sector, which results in the elimination of materials used in its various activities such as containers, packaging, and packaging, among others.

Pyrolysis is a thermal process in which carbon-based compounds, including municipal solid waste (MSW), can be converted into combustible liquids at temperatures ranging from 300 to 600 °C or even higher. The process must be carried out in the total or partial absence of oxygen ($O_2$) (Rehan et al., 2016). The literary review shows various municipal wastes, such as high-density polyethylene (HDPE), low-density polyethylene (LDPE), polystyrene (PS), and polypropylene (PP), which have been treated by thermal and catalytic pyrolysis to obtain fuel liquid (Ali et al., 2011; Cardona & Corma, 2000; Elordi et al., 2009; Garforth et al., 1998; Kim & Kim, 2004; Lin et al., 2010; Miskolczi et al., 2009; Scott et al., 1990; Yoon et al., 1999). According to some researchers, the pyrolysis of PP, HDPE, LDPE, and PS can obtain liquid yields higher than 80%. On the other hand, the product shows characteristics very similar to commercial diesel; density (0.8 MJ/kg), viscosity (above 2.96 $mm^2/s$), cloud point (-18 °C), flash point (30.5) and calorific value (40 MJ/kg(Rehan et al., 2016). Therefore, the pyrolytic liquid has the potential to be used as a fuel liquid for the generation of electrical energy, transport, and thermal machines (Kalargaris et al., 2017a, 2017b, 2018; Miskolczi et al., 2009; Ratio & Engine, 2021).

## METHODS

Different types of plastic waste are found in municipal landfills (MPW), such as polystyrene, high-density polyethylene (HDPE), low-density polyethylene, polypropylene (PP), and mixtures, which have been successfully treated in recycling processes. Catalytic and non-catalytic pyrolysis. The operating conditions such as temperature, residence time, raw material, type of reactor, and composition have been reported and published by various authors.(Aisien et al., 2021; Ali et al., 2011; Anas et al., 2019; Eletta et al., 2017; Onwudili et al., 2009; Vijayakumar & Sebastian, 2018). The average higher calorific value (HHV) is 40 MJ/kg, and the average liquid fuel yield is within the 80% margin. (Sharma et al., 2014), with this, the potential for the generation of electrical energy for the next 20 years (2042) was estimated. Table 1 shows the heating values of some of the everyday plastics that can be commonly found in landfills.

According to the Ministry of the Environment and Natural Resources (SEMARNAT), the generation of municipal solid waste (MSW) in Mexico for the year 2022 was estimated at approximately 120,128 tons/day, which translates into an average of 0.944 kg /inhabitant/day within which 31.56% corresponds to waste that can be used, and of these, 7.66% refers to plastics and 1.55% to expanded polystyrene, that is, approximately 11,051 tons per day (Naturales secretería de Medio Ambiente y Recursos, 2020). On the other hand, according to data obtained from the same SEMARNAT (Residuos Sólidos Urbanos (RSU) | Secretaría de Medio Ambiente y Recursos Naturales | Gobierno | Gob. Mx, n.d.) 83.93% is collected, and of this 78.54% ends up in final disposal sites, and only 9.63% of the total waste is recycled, it is expected

**Table 1.** High heating value (HHV) of some typical plastic waste

| Polymer (resin) | Calorific value (MJ kg-1) | References |
|---|---|---|
| High-density polyethylene (HDPE) | 43 | (Barbarias et al., 2018) |
| Polyethylene (PE) | 43.3-46.5 | (Al-Salem & Lettieri, 2010) |
| Polypropylene (PP) | 46.50 | (Al-Salem & Lettieri, 2010) |
| Polystyrene (PS) | 41.90 | (Al-Salem & Lettieri, 2010) |
| Low-density polyethylene (LDPE) | 46.6 | (Qiao et al., 2018) |
| Expanded polystyrene (EPS) | 41.29 | (Huang et al., 2018) |

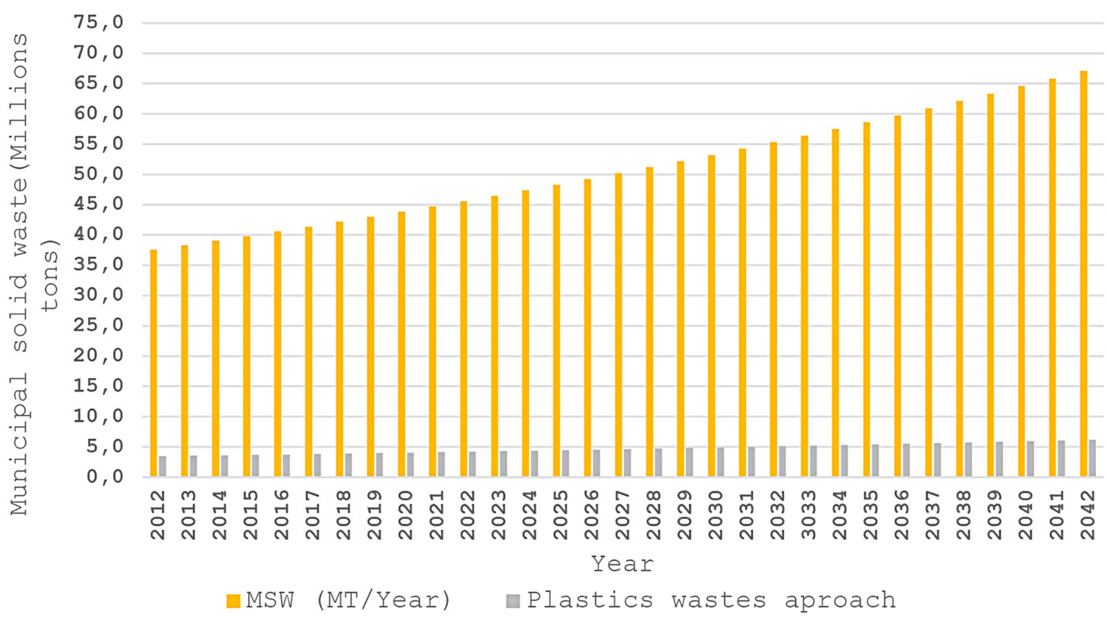


**Figure 1.** Projection in tons of solid waste (2012-2042)

that year after year the waste disposal will increase by an average of 2% (Figure 1).

The municipal solid wastes (MSW) were projected annually from 2022 to 2042, and according to this projection, they amount to more than 67 million tons (Figure 1). The benefits of landfill savings and electricity generation from liquid fuel and coal are considered. Landfill savings were calculated using a basic landfill cost of MXN 121.58 per ton of waste (Residuos Sólidos Urbanos (RSU) | Secretaría de Medio Ambiente y Recursos Naturales | Gobierno | Gob.Mx, n.d.). Electricity savings were calculated based on the typical price of MXN 0.75 per kWh and GHG emissions were calculated using the method proposed by the Intergovernmental Panel on Climate Change (IPPC). The method is described by Equation 1.

$$Q = (MSW_T \times MSW_F \times MCF \times \times DOC \times DOC_F \times F \times \frac{16}{12})(1 - 0X) \quad (1)$$

where: $Q$ – the total $CH_4$ emissions (ton/year);
$MSW_T$ – the total MSW generated per year (ton/year);
$MSW_F$ – the fraction of solids disposed of in landfills;
MCF – a correction factor for methane;
DOC – the degradable carbon fraction;
$DOC_F$ – the dissimilated organic fraction;
F – the gaseous fraction of CH4 in landfills;
16/12 – the molecular weight ratio of methane to carbon;
OX – an oxidation factor.

The details of Equation 1 estimate the emission profiles for methane (CH4) and Mt.CO2 eq. Global warming potential (GWP) has been studied previously and can be consulted in the IPCC guidelines (Reay et al., 2007). The value of carbon is 23. 20 US$ per ton of CO2 equivalent is considered for GHC emission savings (Rehan et al., 2016).

The electrical energy potential was calculated using Equation 2, where PMSW is the electrical potential that can be generated through the pyrolysis of urban plastic waste (GW), MSW is the total urban solid waste generated annually (kg/year), FMSW is a factor that indicates the percentage of solid waste that can be recovered energetically, HHV is the higher calorific power that the plastics that can be recovered contain on average (MJ/kg), FLF is a factor that indicates the fuel liquid yield that can be can recover, tA is the annual time (s).

$$P_{MSW} = (\frac{MSW \times FMSW \times HHV \times FLF}{tA})(1 \times 10^{-9}) \quad (2)$$

## RESULTS AND DISCUSSIONS

According to the projection of municipal solid waste that can be used, by the year 2022, there would be an estimated 45.6 million tons of plastic, which means a potential of 36.48 million tons of liquid fuel, increasing to 54.48 MT in 2042. with a high calorific value of 40 MJ/kg, which translates into a tremendous electrical energy potential of approximately 46.25 GW, with an increase of 2% each year (Figure 2), that is, a

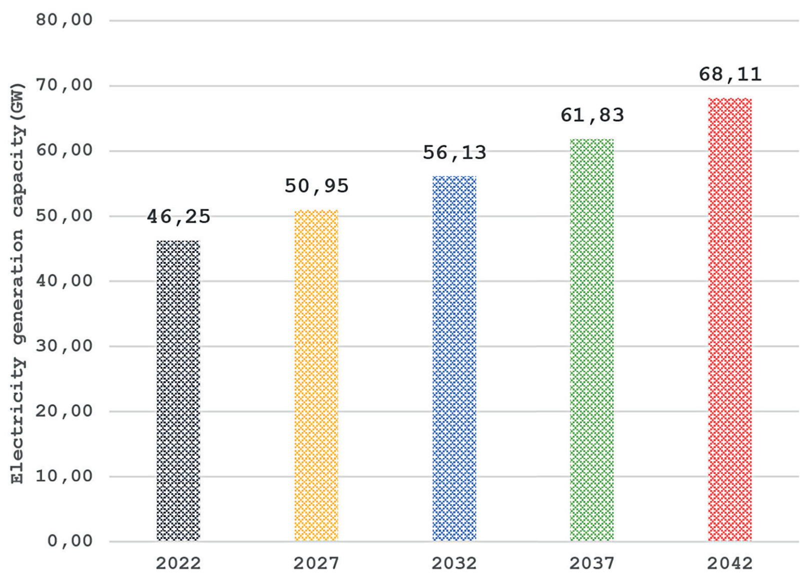


**Figure 2.** Electricity generation capacity through pyrolytic technology using all the plastic waste generated in Mexico

potential of 126.71 MW/day, which can be used to power about 23,038 homes on average (average consumption of 5.5 kW/day).

The economic benefits for savings in fun landfills, electricity generation, and carbon credits tend to be approximately 1,574,622,866.63 US$ with an annual increase of 2%, generating significant economic savings (Figure 3). The Table 2 describes the technical details, economic evaluation, and implementation technique of a pyrolytic technology plant.

**Table 2.** Technical, environmental, and economic evaluation of pyrolytic technology

| Technical details | |
|---|---|
| Adequate waste | MPW, biomass |
| technology complexity | high |
| Skill required by staff | Intermediate |
| Geographic location | industrial/urban area |
| Environmental evaluation | |
| CH4 potential emissions (ton/year) | 2,237,871.22 |
| GWP (Mt.CO2 eq.)[b] | 55,946,780.5 |
| Economic evaluation | |
| Capital cost (ton/year)[a] | $17-$25 |
| Operational cost (ton/year) | $23 |
| Revenue from carbon credits[c] | $1,297,965,307.52[d] |
| Saving from landfill fun | $276,655,824.80[d] |
| Saving from electricity generation | $1,734.31[d] |
| Net revenue | $1,574,622,866.63[d] |

**Note:** [a]According to Rehan et al., [two]; [b]Based on GWP of 25 for methane; [c]At a cost of US$ 23.20/tonnes of $CO_2$, [d]these values are based on 2022 and increase with approximately 2% (Figure 3).

The liquid produced from the pyrolysis of plastic waste also offers the opportunity to be refined and distilled through refining plants, creating alternative fuels for electricity generation or transportation, fuel applications (Demirbas, 2004). In addition, the carbon produced through some chemical modifications can be used in water treatment plants or air purifiers, creating beneficial environmental impacts.

The most significant benefit is the reduction of GHG emissions, contributing to the reduction of greenhouse gases and benefiting society and the environment since this would help reduce the high rates of climate change. In addition, the savings generated from the pyrolysis of MSW can help develop underdeveloped communities by creating direct jobs for the surrounding area and, in turn, increasing the quality of life in these areas.

On the other hand, it should be emphasized that some areas used for waste disposal can be recovered, benefiting the surrounding fauna, and creating green spaces for the different species.

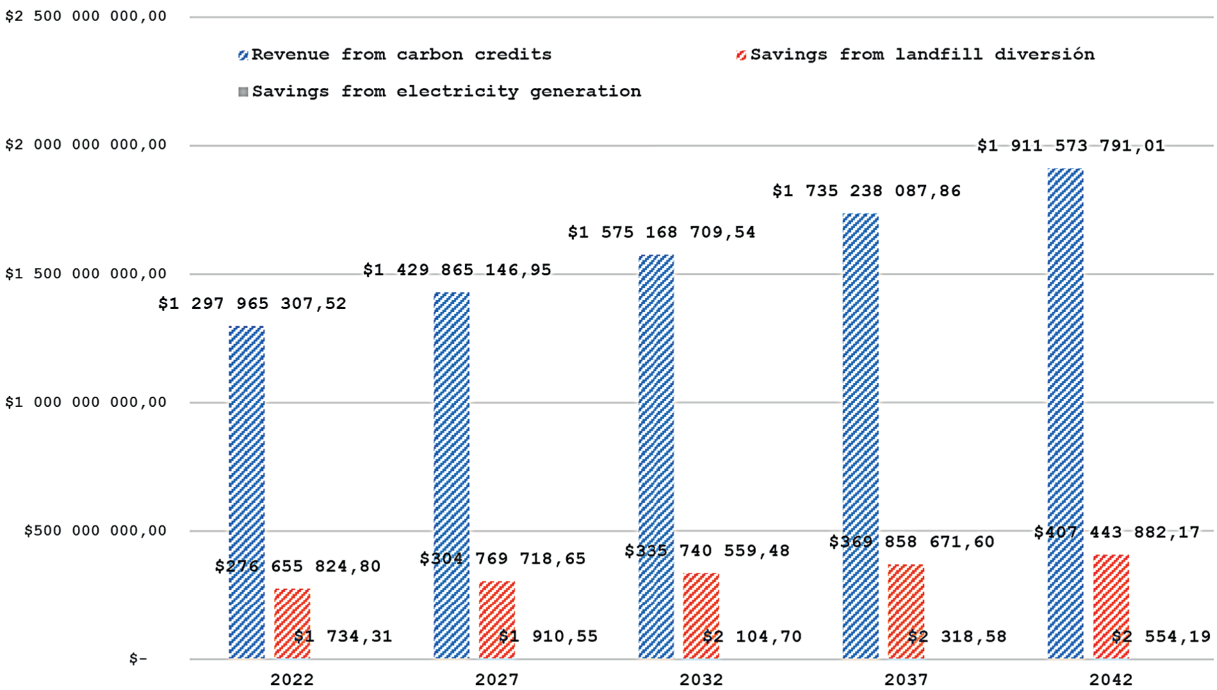


**Figure 3.** Potential savings in millions of US$ from landfill diversion, electricity generation by liquid fuel, and carbon credits from 2022 to 2042

## CONCLUSIONS

The potential of recycling MSW through pyrolysis as an alternative technology in Mexico has been analyzed. The pyrolytic liquid generated from the thermochemical degradation of the waste shows a high energy potential, on average, an HHV of 40 MJ/kg. On the other hand, the liquid fuel shows similar properties to diesel, such as density (0.8 kg/m$^3$), viscosity (on average 2.96 mm$^2$/s), cloud point (-18 °C), flash point (30.5 °C) (Balat, 2008; Kalargaris et al., 2017a; Sharma et al., 2014; Singh et al., 2019). The MSW generated in Mexico for the year 2022 is approximately 45.6 million tons with a projection of 67.1 million tons for 2042, for which the potential for electric power generation would increase proportionally, supplying approximately 23,038 homes. The most crucial part that should be emphasized is the economic savings for landfill diversion, revenue for carbon credits, and electricity generation, which amount to 1,574,622,866.6 US$ with an annual increase of 2%. As observed, the pyrolysis of MSW offers excellent economic, social, and environmental benefits. However, before opting for the implementation of plants, environmental impact studies must be carried out.

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## REFERENCES

1. Aisien, E.T., Otuya, I.C., Aisien, F.A. 2021. Thermal and catalytic pyrolysis of waste polypropylene plastic using spent FCC catalyst. Environmental Technology and Innovation, 22, 101455. https://doi.org/10.1016/j.eti.2021.101455
2. Al-Salem, S.M., Lettieri, P. 2010. Kinetic study of high density polyethylene (HDPE) pyrolysis. Chemical Engineering Research and Design, 88(12), 1599–1606. https://doi.org/10.1016/j.cherd.2010.03.012
3. Ali, M.F., Ahmed, S., Qureshi, M.S. 2011. Catalytic coprocessing of coal and petroleum residues with waste plastics to produce transportation fuels. Fuel Processing Technology, 92(5), 1109–1120. https://doi.org/10.1016/j.fuproc.2011.01.006
4. Anas, M., Jan, K., Munawar, N., Afzal, I., Ali, R., Sirajuddin, K. 2019. Pyrolysis of polypropylene over a LZ - Y52 molecular sieve : kinetics and the product distribution. Iranian Polymer Journal. https://doi.org/10.1007/s13726-019-00747-x
5. Balat, M. 2008. Diesel-like fuel obtained by catalytic pyrolysis of waste engine oil. Energy Exploration and Exploitation, 26(3), 197–208. https://doi.org/10.1260/014459808786933735
6. Barbarias, I., Artetxe, M., Lopez, G., Arregi, A., Bilbao, J., Olazar, M. 2018. Influence of the conditions for reforming HDPE pyrolysis volatiles on the catalyst deactivation by coke. Fuel Processing Technology, 171(September 2017), 100–109. https://doi.org/10.1016/j.fuproc.2017.11.003
7. Cardona, S.C., Corma, A. 2000. Tertiary recycling of polypropylene by catalytic cracking in a semibatch stirred reactor. Use of spent equilibrium FCC commercial catalyst. Applied Catalysis B: Environmental, 25(2–3), 151–162. https://doi.org/10.1016/S0926-3373(99)00127-7
8. Demirbas, A. 2004. Pyrolysis of municipal plastic wastes for recovery of gasoline-range hydrocarbons. Journal of Analytical and Applied Pyrolysis, 72(1), 97–102. https://doi.org/10.1016/j.jaap.2004.03.001
9. Eletta, O.A., Ajayi, O., Ogunleye, O., Tijani, I., Adeniyi, A., Agbana, A. 2017. Identification and Characterisation of Major Hydrocarbons in Thermally Degraded Low Density Polyethylene Films. Journal of Applied Sciences and Environmental Management, 21(6), 1111. https://doi.org/10.4314/jasem.v21i6.20
10. Elordi, G., Olazar, M., Lopez, G., Amutio, M., Artetxe, M., Aguado, R., Bilbao, J. 2009. Catalytic pyrolysis of HDPE in continuous mode over zeolite catalysts in a conical spouted bed reactor. Journal of Analytical and Applied Pyrolysis, 85(1–2), 345–351. https://doi.org/10.1016/j.jaap.2008.10.015
11. Garforth, A.A., Lin, Y.H., Sharratt, P.N., Dwyer, J. 1998. Production of hydrocarbons by catalytic degradation of high density polyethylene in a laboratory fluidised-bed reactor. Applied Catalysis A: General, 169(2), 331–342. https://doi.org/10.1016/S0926-860X(98)00022-2
12. Huang, Y.W., Chen, M.Q., Li, Q.H., Xing, W. 2018. A critical evaluation on chemical exergy and its correlation with high heating value for single and multi-component typical plastic wastes. Energy, 156, 548–554. https://doi.org/10.1016/j.energy.2018.05.116
13. Kalargaris, I., Tian, G., Gu, S. 2017a. Combustion, performance and emission analysis of a DI diesel engine using plastic pyrolysis oil. Fuel Processing Technology, 157, 108–115. https://doi.org/10.1016/j.fuproc.2016.11.016
14. Kalargaris, I., Tian, G., Gu, S. 2017b. The utilisation of oils produced from plastic waste at different pyrolysis temperatures in a DI diesel engine. Energy, 131, 179–185. https://doi.org/10.1016/j.energy.2017.05.024

15. Kalargaris, I., Tian, G., Gu, S. 2018. Experimental characterisation of a diesel engine running on polypropylene oils produced at di ff erent pyrolysis temperatures. Fuel, 211(July 2017), 797–803. https://doi.org/10.1016/j.fuel.2017.09.101
16. Kim, S.S., Kim, S. 2004. Pyrolysis characteristics of polystyrene and polypropylene in a stirred batch reactor. Chemical Engineering Journal, 98(1–2), 53–60. https://doi.org/10.1016/S1385-8947(03)00184-0
17. Lin, H.T., Huang, M.S., Luo, J.W., Lin, L.H., Lee, C.M., 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. https://doi.org/10.1016/j.fuproc.2010.03.016
18. Miskolczi, N., Angyal, A., Bartha, L., Valkai, I. 2009. Fuels by pyrolysis of waste plastics from agricultural and packaging sectors in a pilot scale reactor. Fuel Processing Technology, 90(7–8), 1032–1040. https://doi.org/10.1016/j.fuproc.2009.04.019
19. Naturales secretería de medio ambiente y recursos. 2020. Diagnóstico básico para la gestión integral de los residuos.
20. Onwudili, J.A., Insura, N., Williams, P.T. 2009. Composition of products from the pyrolysis of polyethylene and polystyrene in a closed batch reactor: Effects of temperature and residence time. Journal of Analytical and Applied Pyrolysis, 86(2), 293–303. https://doi.org/10.1016/j.jaap.2009.07.008
21. Qiao, Y., Xu, F., Xu, S., Yang, D., Wang, B., Ming, X., Hao, J., Tian, Y. 2018. Pyrolysis Characteristics and Kinetics of Typical Municipal Solid Waste Components and Their Mixture: Analytical TG-FTIR Study. Energy and Fuels, 32(10), 10801–10812. https://doi.org/10.1021/acs.energyfuels.8b02571
22. Ratio, C., Engine, D. 2021. Characterization and Impact of Waste Plastic Oil in a Variable Compression Ratio Diesel Engine.
23. Reay, D., Sabine, C., Smith, P., Hymus, G. 2007. Intergovernmental Panel on Climate Change. Fourth Assessment Report. Geneva, Switzerland: Inter-gov- ernmental Panel on Climate Change. Cambridge; UK: Cambridge University Press; 2007. Available from: www. ipcc.ch. In Intergovernmental Panel on Climate Change. https://doi.org/10.1038/446727a
24. Rehan, M., Nizami, A.S., Shahzad, K., Ouda, O.K.M., Ismail, I.M.I., Almeelbi, T., Iqbal, T., Demirbas, A. 2016. Pyrolytic liquid fuel: A source of renewable electricity generation in Makkah. Energy Sources, Part A: Recovery, Utilization and Environmental Effects, 38(17), 2598–2603. https://doi.org/10.1080/15567036.2016.1153753
25. Residuos Sólidos Urbanos (RSU) | Secretaría de Medio Ambiente y Recursos Naturales | Gobierno | gob.mx. (n.d.). Retrieved February 1, 2022, from https://www.gob.mx/semarnat/acciones-y-programas/residuos-solidos-urbanos-rsu
26. Scott, D.S., Czernik, S.R., Piskorz, J., Radlein, D.S.A.G. 1990. Fast Pyrolysis of Plastic Wastes. Energy and Fuels, 4(4), 407–411. https://doi.org/10.1021/ef00022a013
27. Sharma, B.K., Moser, B.R., Vermillion, K.E., Doll, K.M., Rajagopalan, N. 2014. Production, characterization and fuel properties of alternative diesel fuel from pyrolysis of waste plastic grocery bags. Fuel Processing Technology, 122, 79–90. https://doi.org/10.1016/j.fuproc.2014.01.019
28. Singh, R.K., Ruj, B., Sadhukhan, A.K., Gupta, P., Tigga, V.P. 2019. Waste plastic to pyrolytic oil and its utilization in CI engine: Performance analysis and combustion characteristics. Fuel, October, 116539. https://doi.org/10.1016/j.fuel.2019.116539
29. Vijayakumar, A., Sebastian, J. 2018. Pyrolysis process to produce fuel from different types of plastic - A review. IOP Conference Series: Materials Science and Engineering, 396(1). https://doi.org/10.1088/1757-899X/396/1/012062
30. Yoon, W.L., Park, J.S., Jung, H., Lee, H.T., Lee, D.K. 1999. Optimization of pyrolytic coprocessing of waste plastics and waste motor oil into fuel oils using statistical pentagonal experimental design. Fuel, 78(7), 809–813. https://doi.org/10.1016/S0016-2361(98)00207-5