Review Paper:

Technologies for sustainable disposal of PSW: A Review

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Abstract
Synthetic plastics have found wide applications in industrial and domestic products. Synthetic plastics are derivatives of fossil fuels and hence they are non-biodegradable. Plastic solid waste (PSW) disposal has posed severe threats to the ecosystem. In this paper, we review the various thermo-chemical recycling technologies of post-consumer PSW. Pyrolysis has been a promising technology in the conversion of PSW into useful hydrocarbon products. Thermal decomposition has achieved decomposition of PSW, but it has not been effective in producing value-added products. Catalytic thermal decomposition of PSW has produced hydrocarbon fuel at lower temperatures and selectivity of reaction has been better than thermal decomposition, but the products of catalytic pyrolysis are not environmentally friendly. The solution for sustainable disposal of PSW is in producing value-added products from decomposition of PSW. Direct incineration of pyrolysis products can produce atmospheric pollution and as well as toxic products for human sustenance.

In this study, we review the technology beyond pyrolysis for the production of value-added products which are sustainable and environmentally friendly. Hydrotreatment of PSW pyrolysis oil using mono metal or bimetal catalysts have shown promising results in the production of value-added products from PSW. Hydro treatment involves hydrocracking, hydrogenation and aromatization of pyrolysis products. Previous studies have shown that metal supported on zeolite supports have produced excellent results.PSW disposal methods should be environmentally friendly and economically viable.

Keywords: Synthetic plastic, pyrolysis, incineration, hydrotreatment and catalyst.

Introduction
Synthetic plastics are polymers derived from hydrocarbons. The worldwide consumption of plastics has reached 360 million tonnes for the year 2018 and since 1990, the production has tripled[1]. The various technologies involved in the disposal of PSW has been shown in figure 1. Direct incineration, landfills are still posing a threat to the environment. Past studies on recycling have shown the degradation of properties of plastics during its lifetime. Recycled products will not give the strength and toughness of the virgin polymer.

Thus, degradation will not be a positive factor for the complete recycling of plastic products.[2] Direct incineration has the possibilities of toxic gaseous products being released into the environment. There is a need to find a solution to prevent the production of toxic products during incineration.[3] Landfills are the worst way of disposing of PSW and more than three fourth of all PSW have ended up in landfills since 1950.[4] Waste plastics have been used to produce roof tiles.[5]

Fig. 1: Technologies for disposal of PSW

Plasma pyrolysis is a promising technology for transforming PSW into synthetic gas. The produced synthetic gas can be used to drive a turbine which generates electricity.[6] Waste HDPE plastic was used as a filler material in the production of concrete and the compression strength was not affected by the addition of the filler.[7]

Liquid fuel production from PSW employs pyrolysis technology to convert the solid waste to liquid carbon products. Pyrolysis is the process of melting and evaporating the solid waste in the absence of oxygen. Liquid fuel production from PSW employs pyrolysis technology to convert the solid waste to liquid carbon products. Pyrolysis is the process of melting and evaporating the solid waste in the absence of oxygen. Pyrolysis process can be performed through two methods, thermal pyrolysis or catalytic pyrolysis. Thermal pyrolysis has been very effective in converting waste plastics to liquid fuel[8]. Thermal pyrolysis employs the application of heat to the PSW products under an inert atmosphere. It has been earlier observed that the reaction temperature ranged from 500 to 600°C. The produced liquid fuel contains alkanes, alkenes and aromatics and attempts have been made to utilise it as fuel for diesel engines.

Catalytic pyrolysis follows a similar procedure, but with an addition of a catalyst to the PSW.[9] The catalyst accelerates the depolymerisation process and improves the selectivity of compounds produced in the resulting fuel oil. The reaction temperatures found in the catalytic process are in the range of 300 to 450°C. The fuel oil obtained from thermal or catalytic process possesses properties which do not match with diesel. The present use for such fuel is mostly confined to incinerators or burners of boilers.

In this paper, we review the previous work on the conversion of PSW pyrolysis oil to alternate diesel fuel.

Results and Discussion

PSW contains polymers of varying melting points and latent heat of evaporation. The process of thermal pyrolysis is shown in figure 2. The PSW constituents are loaded on to a reactor and heated to a temperature of 500 to 650°C. The contents of the reactor are heated under an inert atmosphere to prevent contact with oxygen. The inert atmosphere can also be maintained by employing a vacuum. The reaction time and reaction temperature vary and depend on the percentage presence of various types of polymers in PSW.

The reaction temperature of PSW depends on the activation energy of each constituent of the PSW. PSW polymers contain high carbon number compounds which when pyrolyzed will transform to liquids, but it finally gels to form wax. The limitation of thermal pyrolysis is that it is unable to crack higher carbon compounds to lower compounds. Further, thermal pyrolysis consumes higher power as the reaction temperatures are higher than the catalytic process. The products of thermal pyrolysis are liquid/wax fuel, non-condensable hydrocarbon gases and carbonaceous char.

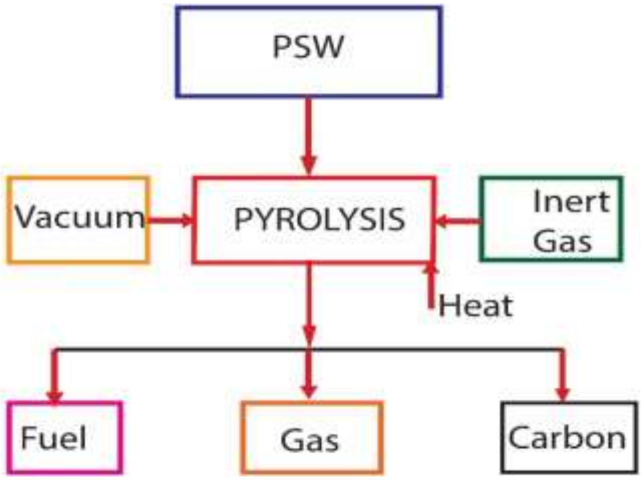

Fig. 2: Layout of thermal pyrolysis of PSW

The process of catalytic pyrolysis is shown in figure 3. The procedure of catalytic pyrolysis is similar to thermal pyrolysis but with an added catalyst. The catalyst enables the pyrolysis process to produce fuel at lower reaction time and temperature. The carbonium ion mechanism enables efficient depolymerisation and cracking.[10-12] The products of catalytic cracking are liquid fuel, gaseous hydrocarbons and carbonaceous char. The catalyst used is mostly zeolites and the process has produced a higher yield of oil than thermal pyrolysis. Catalytic pyrolysis has reduced the reaction time as compared to thermal pyrolysis. Some of the commonly used catalysts are ZSM-5, SBA-15, H-Beta and Mordenite. The products of catalytic pyrolysis contain alkanes, alkenes and aromatics.

The produced fuel from catalytic pyrolysis had been extensively tried in diesel engines and the performance of the fuel doesn't match the commercial diesel fuel performance[13]. The key reason behind this is the presence of alkenes in pyrolysis fuel. Alkenes due to their double bond nature induces high heat release rate (HRR) during combustion in engines. Also, the double bond nature requires high heat energy of evaporation, which results in delayed combustion.

Delayed combustion, high HRR leads to lower thermal efficiency, higher fuel consumption and higher exhaust gas temperatures. Higher exhaust gas temperatures have resulted in higher NOx.[14] The solution to convert the pyrolysis fuel to diesel fuel lies in the composition of the pyrolysis fuel. There is a need to convert the alkenes compounds in pyrolysis fuel to alkanes[15]. Commercial diesel contains alkanes and aromatics. The pyrolysis fuel needs to be treated to match it with diesel.

The hydrotreatment mechanism is shown in figure4. The pyrolysis fuel of PSW possesses heavy carbon elements of saturated and unsaturated molecules. Hydrotreatment of

PSW pyrolysis oil provides the solution for cracking of heavy carbon elements and hydrogenation converts the unsaturated molecules to saturated molecules.[16-19]

Hydrotreatment is conducted inside a reactor with hydrogen gas present at 50 to 80 bar and the temperature of the PSW pyrolysis oil was maintained at 300 to 400 °C. The PSW pyrolysis oil inside the reactor is in contact with a metal impregnated on acidic base support catalyst.[20,21] Hydrotreatment improves the physicochemical properties of the fuel to diesel standards and the hydrotreated fuel has shown diesel-like performance in the diesel engine.[22,23]

Conclusion

Conventional technologies of PSW disposal have been incineration and landfills. Both had severe consequences for the environment. New technologies have provided alternate recycling opportunities for PSW disposal. PSW has been utilised to produce tiles, asphalt layers in road making, concrete production and pyrolysis liquid fuel. PSW pyrolysis fuel has been extensively tried in diesel engines in the past.

The presence of higher carbon elements and unsaturated compounds have produced results which had higher combustion peak pressures and HRR. The emissions of PSW pyrolysis fuel were much higher than commercial diesel. Previous studies show hydrotreated pyrolysis fuel has been successfully produced and tested in the diesel engine. Hydrotreated PSW pyrolysis oil shows a promising option for environmentally safe disposal and energy recovery option.

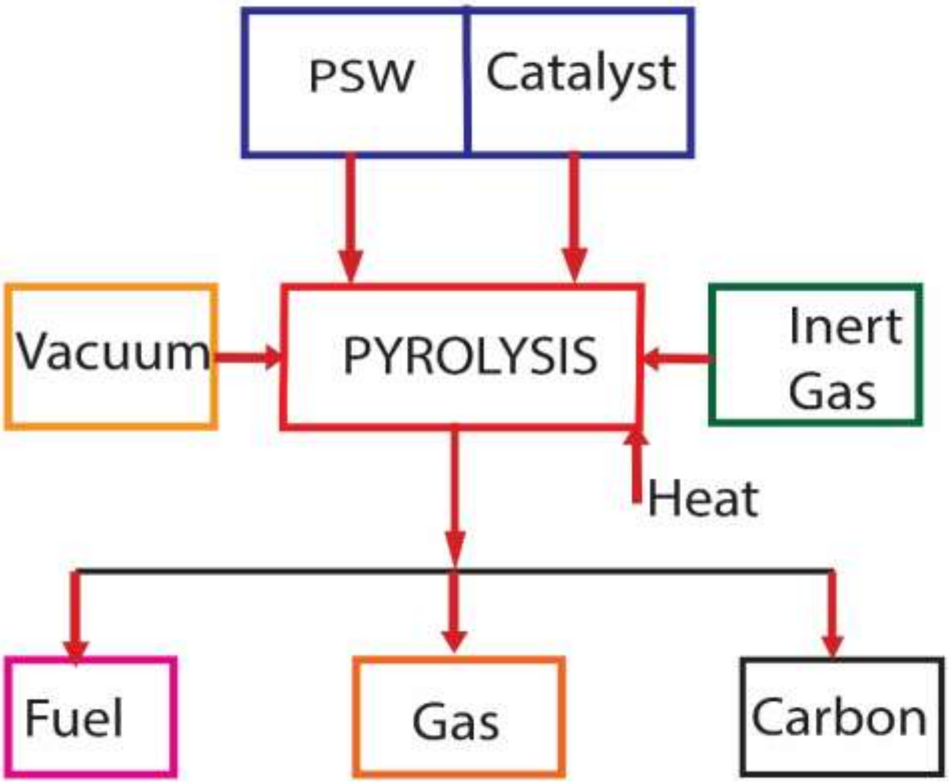

Fig. 3: Layout of catalytic pyrolysis of PSW

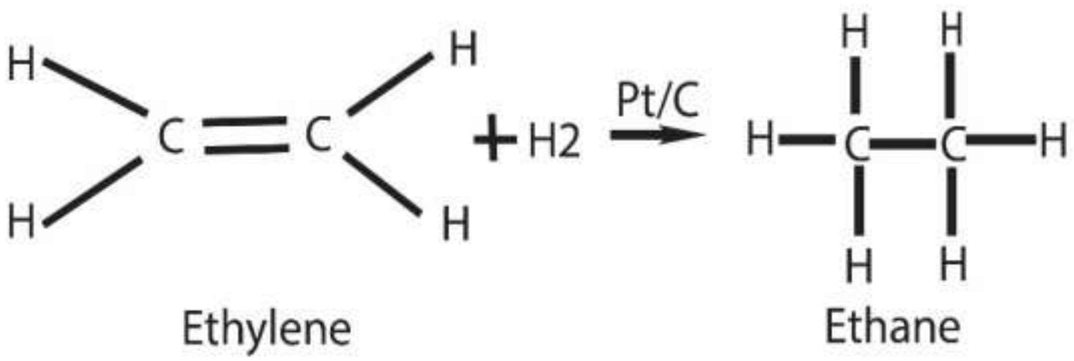

Fig. 4: Hydrogenation mechanism of alkenes

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