Conversion of Plastic Waste into Energy and Value-Added Products in Makkah City

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Abstract

Millions of Muslims from all over the world visit the Holy Cities of Saudi Arabia: Makkah and Madinah every year to perform Hajj and Umrah. The rapid growth in urbanisation and local population of Makkah city along with ever increasing number of visitors result in huge municipal solid waste (MSW) generation every year. Most of this waste is currently dumped into landfill sites without any treatment, thus causing environmental and health issues. For example, on average around 2.4 thousand tons of waste is dumped into Makkah city's landfill sites every day that increases to around 3.1 and 4.6 thousand tons per day during Ramadan and Hajj periods, respectively. Around 23% on average of this waste is plastic waste in the form of plastic bottles, water cups, food plates and shopping bags (Abdul Aziz et al. 2007). A pilot scale catalytic pyrolysis process has been used to convert plastic waste into liquid fuel at Center of Excellence in Environmental Studies (CEES) of King Abdulaziz University, Jeddah. The produced liquid fuel has been found to have high energy value of around 40 MJ/Kg, viscosity of 0.9 mm2/s, density of 0.92 g/cm3, flash point of 30°C, pour point of -18°C and freezing point of -64°C, characteristics similar to conventional diesel. Thus the produced liquid fuel has the potential to be used in several energy related applications such as electricity generation, transportation fuel and heating purposes. It has been estimated that the plastic waste in Makkah city in 2016 could produce around 87.91 MW of electricity with net revenue of 297.52 million SAR. This is projected to increase up to around 172.80 MW of electricity and a total net revenue of 584.83 million SAR by 2040.

Keywords: Pyrolysis technology; Plastic Waste; Liquid Fuel; Makkah; Hajj (Pilgrimage); Umrah; Greenhouse Gas (GHG); Sustainable Environmental Solution (SES)

Introduction

Makkah city has one of the world's largest mosque (Masjid-ul-Haram) and is the centre and holiest place for billions of Muslims all over the globe. Every year, millions of people from all over the world visit Makkah to perform Hajj (Pilgrimage) and Umrah. The number of visitors are increasing with an annual rate of 1.19% from 1993-2014 due to a vast expansion in the Masjid-ul-Haram, increased facilities such as advancement in accommodations, health services, transportation, food and security services Apart from increasing visitors, the local Makkah population is also increasing at a significant rate of 3.15% due to rapid urbanization (Nizami et al. 2015a).

In Makkah city, around 2.4 thousand tons of MSW was produced during the normal days in 2014, which increased to 3.1 and 4.6 thousand tons per day during the Ramadan and Hajj seasons respectively (Nizami et al. 2015a; Nizami et al. 2014b). The plastic waste is the second largest waste stream (around 23%) and consist of plastic bottles, water cups, food plates and shopping bags etc. (Nizami et al. 2015a). Most of this waste is currently dumped into landfill sites without any treatment. The plastic waste causes disposal and environmental challenges over landfills due to its clogging effects, very slow biodegradation and presence of toxic additives etc. (CDSI, 2011; Ouda and Cekirge, 2014).

The Saudi government is improving its services and waste management practices with time. Recently the government initiated the practices of reducing, recycling and reusing concepts to limit the MSW generation (Ouda et al., 2013). However, the rapid rate of waste generation in a limited time and space like during Hajj and Ramadan seasons requires special procedures to be implemented close to the waste sources in Makkah city (Nizami et al., 2015b). Moreover, the selected techniques for the treatment of such huge waste must also be economic and environment friendly (Nizami et al. 2014a; Nizami et al., 2015c; Nizami et al. 2016; Sadaf et al. 2015). Pyrolysis technology has the potential to treat the second largest waste stream of plastic in Makkah city into liquid fuel and other valuable products (Ouda et al., 2015; Rehan et al. 2016).

This paper is the first of its kind to propose a sustainable solution for treating the huge plastic waste produced in Makkah city, especially during Hajj and Umrah seasons. A technical, environmental and economic analysis of converting all the plastic wastes into liquid fuel and other valuable products using pyrolysis technology is given. Furthermore, the energy contents of liquid fuel and potential of generating electricity from this renewable source has been calculated for next 25 years up to 2040.

Methodology

Pyrolysis process is a thermal process in which different types of plastic can be converted into liquid fuel and other valuable products at high temperatures in a closed reactor with no oxygen. A small pilot scale (20 L reactor capacity) pyrolysis process has been set-up at the Center of Excellence in Environmental Studies (CEES) at King Abdulaziz University (Figure 1). Basically the plastic waste is cut into small pieces and heated up in the reactor at temperature range of 400-600°C. The plastic is melted and then vaporised into organic vapours that move from reactor into catalytic chamber and then through condenser unit, in which they are liquefied using a chiller unit. The detailed design and specification of this process can be found in previous work (Miandad et al. 2016).

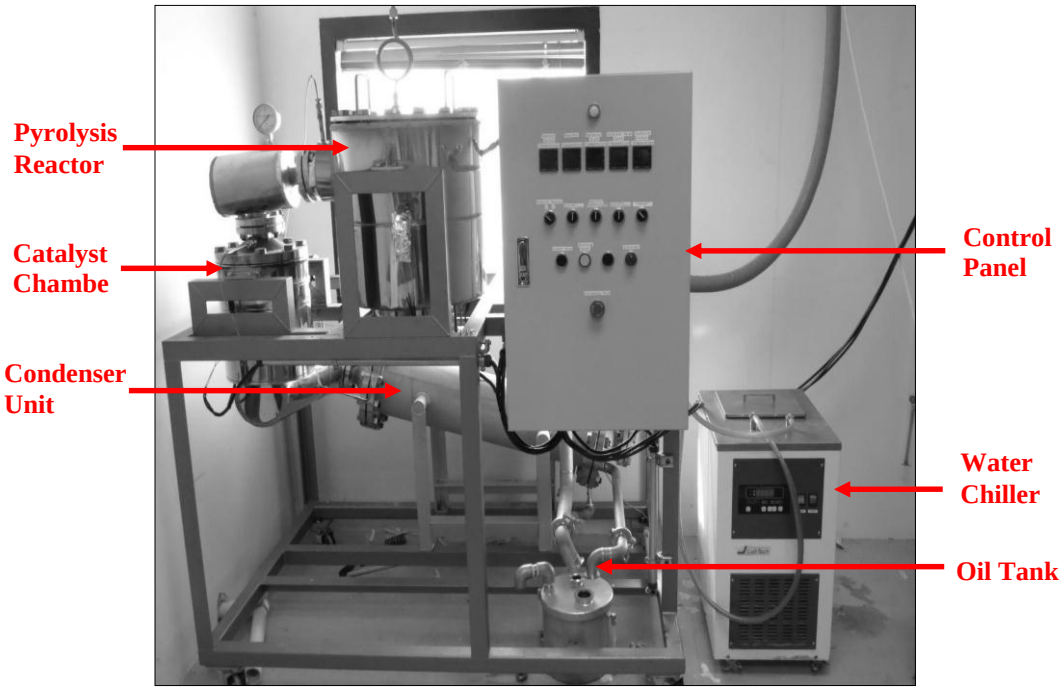

Figure 1: Pilot scale batch catalytic pyrolysis process at CEES (Miandad et al. 2016)

Different types of plastic waste such as polyethylene (PE) (both high density and low density polyethylene), polyethylene terephthalate (PET), and polystyrene (PS) have been treated and converted into liquid fuel, char and gases. The plastic products include plastic plates, glasses, bottles, shopping bags etc. The plastic waste was collected from different sources including household, canteens, hotels and Jeddah landfill sites. Each plastic type was studied separately as well as a mixture with other plastic types to study their effect on the yield and quality of produced liquid fuel and other by-products.

The quality of the produced liquid fuel has been further assessed by its energy contents, viscosity, density, pour point, freezing point etc. As per the focus of this paper, the energy contents in terms of high heating values (HHV) of the liquid fuel produced from different plastic types and different process conditions have been extensively studied using a state-of-the-art automatic bomb calorimeter from Koehler.

Results and Discussion

Plastic waste generation rates in Makkah city

The waste produced in Makkah city is significantly increasing every year due to increase in local population and the number of pilgrim visitors every year. The annual increase in the rate of Makkah population (3.15%) and in the number of pilgrims (1.19%) together with total MSW waste produced in 2014 was taken from previous published work (Nizami et al. 2015a). The total MSW estimated to be produced in 2016 is around 1.414 million tons; of which 0.937 million tons by 1.833 million local people, 0.123 million tons by 2.155 million Hajj pilgrims and 0.123 during Ramadan. The waste calculations were based on 1.4 kg/person/day for 365 days by local population, 1.9 kg/person/day for 30 days by Hajj pilgrims and 2/3 of waste during hajj for 30 days by locals and visitors in Ramadan (Nizami et al. 2015a). The MSW was then annually projected from the year 2016 up to 2040 to reach 2.244 million tons. The plastic waste stream accounts for about 23% which makes 0.263 and 0.516 million tons of plastic waste in 2016 and 2040 respectively.

The King Abdullah expansion project of Masjid-ul-Haram is expected to be completed by 2020, which will significantly increase the capacity for worshipers, resulting in increased number of visitors. However, due to the lack of accurate data for new capacity and expected increase in visitors, currently the annual increase rate is taken as normal 1.19% based on published data (Nizami et al. 2015a). Nevertheless, the actual figures will ultimately result in more waste and thus further increasing the potential of the current proposed solution for waste treatment by producing more electricity and economic benefits.

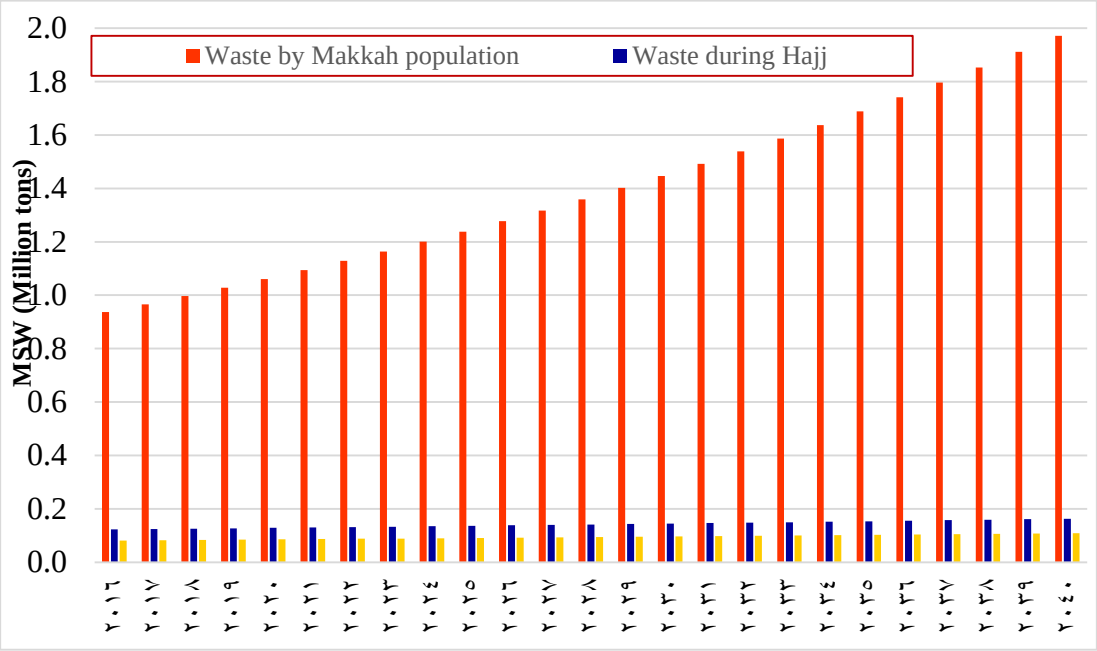

Figure 2: Perojection of total MSW generation by Makkah population, during Hajj and Umrah seasons from 2016-2040

Production of liquid fuel from plastic waste

Different types of plastic waste has been successfully treated in pyrolysis process and converted into liquid fuel and char. Although a range of process conditions such as temperature, retention time, feed stock type and composition and so on have been studied in detail and the results are published earlier (Miandad et al. 2016). The optimum pyrolysis process conditions have resulted in an average liquid fuel yield of around 80%. This means the total plastic waste of 0.263 million tons has the potential to produce 0.210 million tons of oil in 2016. The amount of liquid fuel will increase every year due to increase in plastic waste and will reach up to 0.412 million tons from the 0.516 million tons of plastic waste in 2040.

The produced liquid fuel has been found to have high energy value of around 40 MJ/Kg, viscosity of 0.9 mm2/s, density of 0.92g/cm3, flash point of 30°C, pour point of -18°C and freezing point of -64°C, characteristics similar to conventional liquid fuel (Miandad et al. 2016). This fuel thus has the potential to be used in a number of energy related applications such as electricity generation, transportation fuel and heating purpose.

Electricity generation from pyrolytic liquid fuel

The high HHV of 40 MJ/Kg of liquid fuel produced from plastic waste using pyrolysis process has a great potential to be used for electricity generation. So for, 0.8 Kg of liquid fuel has around 32 MJ or 8.89 KWh (since 3.6 MJ are equivalent to 1 KWh) of

energy potential. Thus the total amount of 0.263 million tons of liquid fuel has energy potential of 2334000 MWh of energy potential. This means it is possible to generate around 87.91 MW of continuous power supply with standard 33% electricity generating plant. This power capacity will again increase every year and will reach up to 172.80 MW in 2040 (Figure 3).

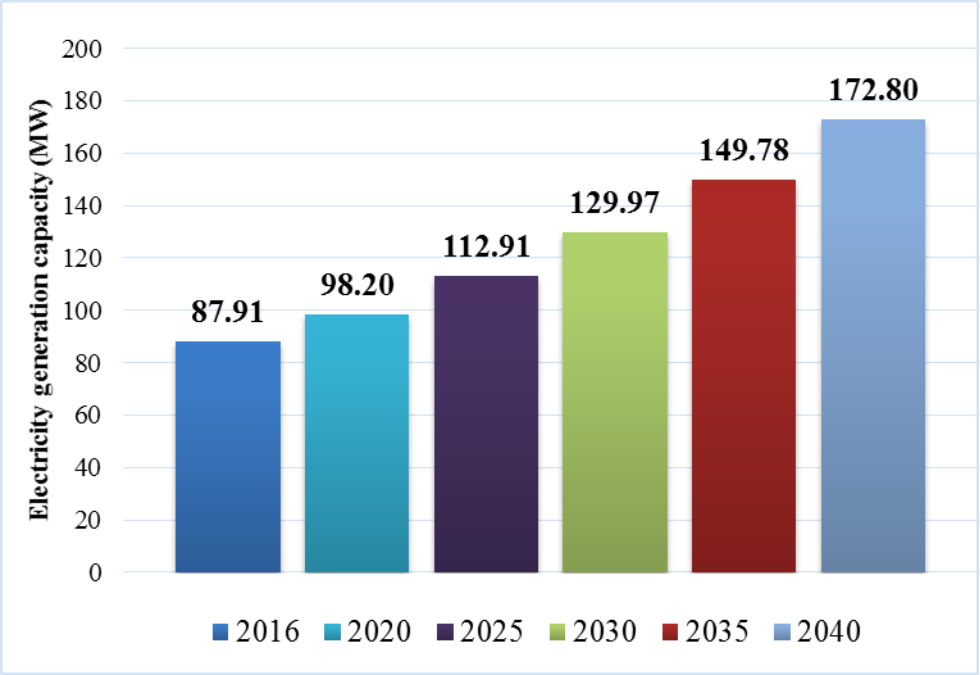

Figure 3: Electricty generation capacity from pyrolysis technology utilizing the complete plastic waste stream from 2016-2040

Economic and environmental benefits of pyrolysis technology

The proposed pyrolysis technology has the potential to operate at large scale and treat and convert all the plastic waste in controlled conditions into liquid fuel and useful products. This will not only help to reduce the environmental pollution but also will generate significant economic benefits. Currently only the main economic benefits such as savings from landfill diversion, electricity generation from pyrolytic produced liquid fuel and carbon credits are considered. The landfill diversion savings were calculated on the basis of savings of 572.36 SAR per ton of waste to be landfilled. The savings from electricity was based on the current price of 0.26 SAR per KWh. Finally the GHG emissions were calculated by using the method proposed by Intergovernmental Panel on Climate Change (IPPC) and Carbon credit value of 23.20 US$ per ton CO2 equivalent is considered for GHG emission savings (Noor et al. 2012). Using these parameters, the savings of 150.26, 120.13 and 27.13 (total 297.52) million SAR from landfill diversion, electricity generation and carbon credits

respectively would be possible in 2016. This economic benefit will increase every year and will reach up to 295.36, 236.14 and 53.33 (total 584.83) million SAR respectively in 2040 (Figure 4).

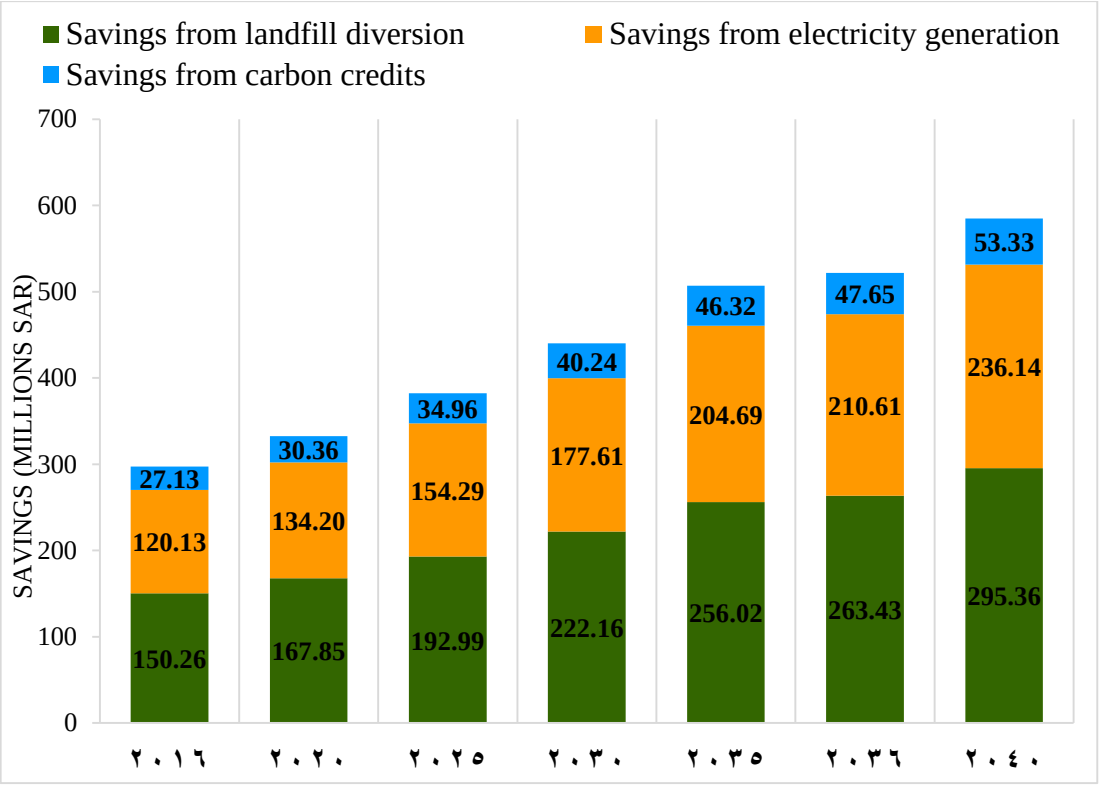

Figure 4: Potential savings in millions SAR from landfill diversion, electricty generation by liquid fuel and carbon credits from 2016-2040

The produced liquid fuel can be further treated and utilized for other energy demanding applications or in transportation. The produced char with some modification has a wide of range of applications including wastewater treatment and air purification from toxic pollutants and thus it can generate significant amounts of revenue. The land saved from waste dumping can be utilize for agriculture or other useful meanings. The reduced GHG emissions will ultimately contribute and help to tackle the global warming and climate change effect at a significant level. Nevertheless, the improved environmental conditions will certainly improve the public health, saving millions of SAR every year.

Conclusions

The potential of pyrolysis technology to treat all the plastic waste produced in Makkah city has been studied. A pilot scale pyrolysis process with a capacity of 20 L has been set up and used to convert plastic waste into liquid fuel and other useful products such as char and gases. The liquid fuel produced from thermal cracking of different types of plastic waste has an average HHV of 40 MJ/Kg. The liquid fuel other characteristics such as viscosity (0.9 mm^2/s), density (0.92 g/cm^3), flash point (30°C), pour point (-18°C) and freezing point of (-64°C) were found to be similar to conventional diesel. The MSW generated in Makkah city by the local population, pilgrims and during Ramadan has been estimated to be 1.141 million tons in 2016 and projected yearly to reach up to 2.244 million tons in 2040. The plastic waste stream is around 23% of the MSW and if all the plastic waste is treated by pyrolysis process, it has the potential to produce around 87.91 MW of electricity from 210.02 million kg of produced liquid fuel and savings of 150.26, 120.13 and 27.13 (total 297.52) million SAR from landfill diversion, electricity generation from liquid fuel and carbon credit, respectively. The electricity generation and the savings from pyrolysis technology will increase every year as the Makkah population, pilgrims and MSW increases. This is projected to increase up to around 172.80 MW of electricity and a total income of 584.8 million SAR by 2040. The pyrolysis technology seems a promising and sustainable solution to treat the plastic waste stream of Makkah city. However, more in depth studies are required including factors like socio-economics, local conditions, culture and current practices to be carefully considered before taking the final decision on adapting the pyrolysis technology.

Further Research

- The produced liquid fuel can be further treated to clean and improve its quality.
- A detailed feasibility study including economic, environmental and technical aspects of pyrolysis technology is needed for understanding the full potential and benefits of adapting this technology is Makkah to treat all plastic waste.
- A complete material and energy balance of pyrolysis process at industrial scale would help detailed feasibility study.
- A comprehensive study to highlight the detrimental impacts of plastic waste, on environment and human beings, as dumped in landfill sites would help the decision maker in taking the right decision.
- Undertaking Life Cycle Assessment (LCA) on plastic materials and pyrolysis technology for under pinning the benefits and environmental benefits of this technology.

- Investigation of socio-economics, local conditions, culture and current practices together with the above recommended research areas is also very important to be carefully considered before taking the final decision on choosing the pyrolysis technology as a sustainable solution for treatment of waste in Makkah city.

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