Usability of Municipal and Medical Waste Plastics as a Fuel in Diesel Engines

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Abstract: The basic aim of this study was to examine the usability of plastic municipal and medical waste as an alternative source to diesel engines. For this study; waste plastic materials, obtained from Adana Metropolitan Municipality dumping site and medical wastes from Adana State Hospital were used. Waste plastics were transformed to waste plastic fuel by thermal cracking. Municipal and medical waste plastic fuels without bleaching process were blended with diesel fuel at volumetric ratios of 10%, 20% and 50%. Fuel properties of waste plastic fuels and its blends with diesel fuel were analysed in accordance with the standards of American Society for Testing and Materials (ASTM) methods. In addition to fuel properties, engine performance and exhaust emission tests of waste plastic fuel and diesel fuel blends were performed.

Key-Words: Engine performance, emissions, fuel properties, municipal and medical waste, plastic fuel

1 Introduction

Economic growth, changing consumption and production patterns are resulting into rapid increase in generation of waste plastics in the world. In Asia and the Pacific, as well as many other developing regions, plastic consumption has increased much more than the world average due to rapid urbanization and economic development.

The world’s annual consumption of plastic materials has increased from around 5 million tons in the 1950’s to nearly 100 million tons; thus, 20 times more plastic is produced today than 50 years ago. This implies that on the one hand, more resources are being used to meet the increased demand of plastic, and on the other hand, more plastic waste is being generated.

Due to the increase in generation, waste plastics are becoming a major stream in solid waste. After food waste and paper waste, plastic waste is the major constituent of municipal and industrial waste in cities. Even the cities with low economic growth have started producing more plastic waste due to plastic packaging, plastic shopping bags, PET bottles and other goods/appliances using plastic as the major component.

This increase has turned into a major challenge for local authorities, responsible for solid waste management and sanitation. Due to lack of integrated solid waste management, most of the plastic waste is neither collected properly nor disposed of in appropriate manner to avoid its negative impacts on environment and public health and waste plastics are causing littering and choking of sewerage system. On the other hand, plastic waste recycling can provide an opportunity to collect and dispose of plastic waste in the most environmental friendly way and it can be converted into a resource. In most of the situations, plastic waste recycling could also be economically viable, as it generates resources, which are in high demand. Plastic waste recycling also has a great potential for resource conservation and GHG emissions reduction, such as producing diesel fuel from plastic waste. This resource conservation goal is very important for most of the national and local governments, where rapid industrialization and economic development is putting a lot of pressure on natural resources. Some of the developed countries have already established commercial level resource recovery from waste plastics. Therefore, having a “latecomer’s advantage”, developing countries can learn from these experiences and technologies available to them [1].

Healthcare waste is all the waste generated by healthcare facilities, medical laboratories and biomedical research facilities, as well as waste from minor or scattered sources. The bulk of healthcare waste is produced by hospitals. Improper treatment
and disposal of healthcare waste pose serious hazards of disease transmission due to exposures to infectious agents among waste pickers, waste workers, health workers, patients, and the community in general. Open burning and incineration without adequate pollution control expose waste workers and the community to toxic contaminants in air emissions and ash [2].

Health-care waste comes from many sources, including major sources such as hospitals, clinics and laboratories, as well as minor sources such as doctor’s offices, dental clinics and convalescent homes. Between 75% and 90% of the waste produced by health-care facilities is non-hazardous or general health-care waste, and only 10% to 25% of health-care waste has a hazard that requires careful management. A significant portion of non-hazardous, general waste is recyclable or compostable [3].

Health-care waste management, as well as posing technical problems, is strongly influenced by cultural, social, and economic circumstances. A well designed waste policy, a legislative framework, and plans for achieving local implementation are essential. Change will be gradual and should be technically and financially sustainable in the long term [4].

The basic aim of this study was to examine the usability of plastic municipal and medical waste as an alternative source to diesel fuel.

2 Municipal Solid Waste Situation in Turkey and Adana

In accordance with Law on Environment, Solid Waste Management Regulation, Metropolitan Municipalities Law and Municipal Law; metropolitan municipalities and municipalities out of adjacent zones and the highest civilian authority out of these zones are responsible for ensuring the disposal of domestic and domestic type industrial solid waste while avoiding environmental damage, waste while avoiding environmental damage, ensuring the maximal use of the landfills and ensuring the classification and separation of recyclable solid waste to contribute to the economy and taking relevant measures to ensure these.

Municipalities, while fulfilling their duties in collecting and transporting the solid waste to a great extent, cannot show the required level of activity and attention in disposal within solid waste management. The great majority of the solid waste in the country is still not being disposed in accordance with the legislation. There exist many administrative, financial and technical reasons contributing to this existing situation. Especially unsanitary disposal, errors in selection of the disposal sites and the drawbacks in administration are causing ever increasing problems.

In solid waste production, primarily the amount of waste produced should be reduced. Moreover, the need for awareness rising in households for separation of waste at the source, to make it ready for collection, is ongoing.

Existence of many local administrative units in the same region makes it compulsory to have cooperation and coordination in solid waste services like in other infrastructural services. Local administrative union model applications, as promoted by the new legislation, come up as facilitating bodies for realization of local-level environmental services.

Solid waste in Turkey is generally discharged to unsanitary landfill sites in an uncontrolled manner [5].

Turkey’s first municipal waste composition studies are made by State Institute of Statistics Turkey at 1993. Studies on establishment of a nation-wide effective solid waste management system have been initiated. In this regard, Solid Waste Master Plan for the domestic-type waste is completed and further studies are ongoing for development of the National and Regional Waste Management Plan for other waste types.

“The Solid Waste Master Plan Project”, implemented under coordination of Ministry of Environment and Forestry (MOEF) and Undersecretaries of State Planning Organization in 2006, has aimed at establishment of unions between municipalities for solid waste disposal across Turkey, development of economically sustainable Regional Solid Waste Facilities and ensuring the implementation of the projects within a plan. As foreseen by the relevant legislation, plans are developed for the establishment of sanitary landfill sites, reduction of amount of produced solid waste, ensuring recycling, reduction of solid waste transport costs and use of transport sites equipped with appropriate technologies where deemed necessary; 16 type of projects are developed in this regard so as to provide guidance to municipalities.

MOEF’s estimation of domestic solid waste production in 2008, calculated through per capita waste estimates, is 26.8 million tons. 13.3 million tons of these wastes are disposed in sanitary landfills while 0.3 million tons are processed in compost facilities. The numbers of sanitary landfill sites in operation have risen to 41 by 2009.

MOEF have carried out various regional fieldworks in order to determine the domestic waste
composition of households in Turkey in addition to solid waste surveys sent to cities that are representative of Turkey. The outcome of these studies, municipal waste composition in Turkey is shown in Fig. 1.

Fig. 1. Composition of domestic wastes in Turkey [6].

Municipal waste compositions of Adana are 64.4% of municipal wastes are organic, 14.8% % of municipal wastes are paper/board, 5.92% % of municipal wastes are plastics, 1.4% % of municipal wastes are metal, 3.08% % of municipal wastes are glass and 10.4% % of municipal wastes are others (wastes of electric and electronic equipment’s, construction and demolition wastes etc.) [7].

3 Medical Waste Situation in Turkey and Adana

The management of the health-care wastes in Turkey is one of the environmental subjects to be considered. The amount of waste from health-care facilities in Turkey is a significant portion of the total waste generated and therefore requires efficient management and control systems by a specific regulation.

Health-care wastes are potential sources of risk to public health mostly in the middle and lower-income countries. Although central governments in these middle and low income countries are often keen to legislate against environmental pollution, they cannot implement the published legislation because of the lack of financial resources [8].

Wastes collected in medical institutions must be stored in temporary waste storage or containers until they are collected by the municipality.

Transportation of medical wastes from temporary storage sites and containers as well as small sources to disposal sites are being carried out by entities and enterprises as authorized by the municipalities.

Medical Waste Control Regulation paved the path for implementation of alternative disposal technologies for the disposal of medical waste in Turkey. MOEF has instructed the municipalities to handle domestic solid waste and medical waste disposal in an integrated manner, to consider the medical waste disposal as a component and to prioritize sterilization as the best means of intermediate processing method as per country’s circumstances.

Medical institutions are paying due attention on separation of medical waste from other solid waste at its source, transportation and temporary storage. Equally, municipalities as well have made progress in proper disposal of the medical waste [5].

68,928,799 kg medical wastes were collected from 1,449 health institutions in Turkey in 2012. 46% of medical wastes were sterilized and disposed at controlled landfill site, 28% of medical wastes were not sterilized and were disposed at controlled landfill site, 16% of medical wastes were sterilized and disposed at municipal dumping site, 1% of medical wastes were not sterilized and were disposed at municipal dumping site, and 8% of medical wastes were disposed with the incinerator. 2,959,837 kg medical wastes were collected from 26 health institutions in Adana in 2012 and nearly all medical wastes in Adana were sterilized and disposed at Adana Metropolitan Municipality dumping site [9].

4 Material and Method

For this study, a pilot cracking reactor which has a 20 litres maximum capacity (Fig. 2) was designed and manufactured for waste plastics cracking. Reactor consists of heat exchanger, PT100 type thermocouple in order to measure the variation of temperature inside the reactor, digital temperature indicator, filler cap, drain cover and manometer. Stainless steel 316L is used as the main material for reactor manufacturing.

Fig. 2. Thermal cracking reactor

Technical drawing of the thermal cracking reactor is shown in Fig. 3.
During the thermal cracking process, the reactor was heated up to the reaction temperature of 450°C and temperature controller was set to this temperature. One and half hour reaction times allowed when the temperature reached to the adjusted reaction temperature. The digital temperature controller sensitivity of reactor was observed as ±10°C. After thermal cracking reaction, the gaseous form occurred, then the gaseous form was transformed the liquid form by using plate type heat exchangers. The product was distillated into a receiver and finally the final product was taken from the receiver (Fig. 6).

In this study, three different municipal and medical waste plastic fuel blends were prepared by mixing diesel fuel (DF) at volumetric ratios of 10%, 20% and 50%. The blends have been analysed by the standards of ASTM test methods. In the engine experiment, Mitsubishi 4D34-2A type four stroke-four cylinder diesel engine, which has 3907 cc engine volume, 89 kW maximum power at 3200 rpm and 295 Nm at 1800 rpm, has been used. Brake torque and brake power of the engine were measured with dynamometer. Exhaust emissions were measured by Testo 350XL gas analyser. All engine experiments were repeated 3 times.
5 Result and Discussion

5.1 Fuel Properties

Measured fuel properties of Municipal Waste Plastic Fuel (MUNWP) and its blends are shown in Table 1.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Diesel Fuel</th>
<th>MUNWP</th>
<th>MUNWP</th>
<th>MUNWP</th>
<th>MUNWP</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>20</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Density (kg/lt)</td>
<td>0.830</td>
<td>0.838</td>
<td>0.847</td>
<td>0.866</td>
<td>0.891</td>
</tr>
<tr>
<td>Cetane Number</td>
<td>55.57</td>
<td>53.64</td>
<td>52.35</td>
<td>51.49</td>
<td>48.58</td>
</tr>
<tr>
<td>Pour Point (°C)</td>
<td>-16.0</td>
<td>-13.5</td>
<td>-11.0</td>
<td>-6.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Viscosity (cSt)</td>
<td>2.45</td>
<td>2.44</td>
<td>2.43</td>
<td>2.41</td>
<td>2.37</td>
</tr>
<tr>
<td>Calorific Value (kcal/kg)</td>
<td>11,320</td>
<td>11,020</td>
<td>10,942</td>
<td>10,740</td>
<td>10,150</td>
</tr>
<tr>
<td>Flash Point (°C)</td>
<td>70.5</td>
<td>70.5</td>
<td>70.5</td>
<td>70.5</td>
<td>70.5</td>
</tr>
</tbody>
</table>

Measured fuel properties of Medical Waste Plastic Fuel (MEDWP) and its blends are shown in Table 2.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Diesel Fuel</th>
<th>MEDWP</th>
<th>MEDWP</th>
<th>MEDWP</th>
<th>MEDWP</th>
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<tr>
<td></td>
<td></td>
<td>10</td>
<td>20</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Density (kg/lt)</td>
<td>0.830</td>
<td>0.845</td>
<td>0.858</td>
<td>0.894</td>
<td>0.940</td>
</tr>
<tr>
<td>Cetane Number</td>
<td>55.57</td>
<td>54.52</td>
<td>53.20</td>
<td>51.48</td>
<td>46.58</td>
</tr>
<tr>
<td>Pour Point (°C)</td>
<td>-16.0</td>
<td>-13</td>
<td>-10.5</td>
<td>-6.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Viscosity (cSt)</td>
<td>2.45</td>
<td>2.42</td>
<td>2.41</td>
<td>2.39</td>
<td>2.30</td>
</tr>
<tr>
<td>Calorific Value (kcal/kg)</td>
<td>11,320</td>
<td>11,105</td>
<td>10,980</td>
<td>10,650</td>
<td>9,850</td>
</tr>
<tr>
<td>Flash Point (°C)</td>
<td>70.5</td>
<td>65.5</td>
<td>65.5</td>
<td>65.5</td>
<td>65.5</td>
</tr>
</tbody>
</table>

Generally, waste plastic fuels have high pour points. High pour point of a fuel can show disquieting problems about transferring, storing and using in cold weather. To add the MUNWP to the blends caused an increment in the pour point values.

Fuel property experiments showed that, MUNWP has lower viscosity value than diesel (2.37 and 2.45 mm²/s respectively). It is observed that, MUNWP addition to diesel caused a decrease in the viscosity values. It shows that MUNWP can flow easier than diesel fuel.

The flash point of a fuel is the lowest temperature at which it can form an ignitable mix with air. The flash point is an important value for the safe transportation and storage of the fuel. The experiments showed that MUNWP has same flash point with diesel so that all blends have same flash point with diesel.

Only 10% MUNWP and MEDWP blends with diesel fuel can comply with EN 590 diesel fuel standards. When the ratio of MUNWP and MEDWP increases in the mixture; density, Cetane number and Pour Point values of the blends goes out of the EN 590 diesel fuel standard.

5.2 Engine Performances

Brake power output values of diesel fuel, 10%, 20% and 50% MUNWP and MEDWP blends are illustrated in Fig. 8 and Fig. 9. Brake torque output values of diesel fuel, 10%, 20% and 50% MUNWP and MEDWP blends are illustrated in Fig. 10 and Fig. 11.
The characteristics of power and brake torque curves were not changed, according to the type of fuel. It was observed that the maximum power values of diesel was obtained at 2400 rpm and the maximum power values of MUNWP and MEDWP blends were obtained almost 5% lower engine speeds. Brake power and brake torque values of MUNWP and MEDWP blends are lower than diesel fuel because of the lower calorific values of MUNWP and MEDWP.

5.3 Exhaust Emissions

CO values of diesel fuel, 10%, 20% and 50% MUNWP and MEDWP blends are illustrated in Fig. 12 and Fig. 13. CO₂ values of diesel fuel, 10%, 20% and 50% MUNWP and MEDWP blends are illustrated in Fig. 14 and Fig. 15. Similarly NOₓ values of diesel fuel, 10%, 20% and 50% MUNWP and MEDWP blends are illustrated in Fig. 16 and Fig. 17.

Generally, CI engine operates with lean mixtures and hence the CO emission would be low. CO emission is toxic and must be controlled. It is an intermediate product in the combustion of a hydrocarbon fuel, so its emission results from incomplete combustion. Emission of CO is therefore greatly dependent on the air fuel ratio relative to the stoichiometric proportions. Rich combustion invariably produces CO, and emissions increase nearly linearly with the deviation from the
The concentration of CO$_2$ in Earth’s atmosphere has increased during the past century. CO$_2$, a greenhouse gas, is the main pollutant that is warming Earth. Though living things emit carbon dioxide when they breathe, carbon dioxide is widely considered to be a pollutant when associated with cars, planes, power plants, and other human activities that involve the burning of fossil fuels such as gasoline and natural gas. In the past 150 years, such activities have pumped enough carbon dioxide into the atmosphere to raise its levels higher than they have been for hundreds of thousands of years. On a larger scale, governments are taking measures to limit emissions of carbon dioxide and other greenhouse gases. One way is through the Kyoto Protocol, an agreement between countries that they will cut back on carbon dioxide emissions. Another method is to put taxes on carbon emissions or higher taxes on petroleum fuels so that people can pollute less. CO$_2$ values of MUNWP and MEDWP blends are lower than diesel fuel because of lower ratio of Carbon atoms in the MUNWP and MEDWP fuels than diesel fuel.
The oxides of nitrogen in the emissions contain nitric oxide (NO) and nitrogen dioxide (NO₂). The formation of nitrogen oxides (NOₓ) is highly dependent on in-cylinder temperature, oxygen concentration and residence time for the reactions to take place. NOₓ values of MUNWP and MEDWP blends are higher than diesel fuel because of the better atomization creates higher combustion temperature in the engine cylinder. NOₓ emissions are only dependent on in-cylinder combustion temperature.

6 Conclusion
In this study, municipal and medical waste plastics were transformed to plastic fuel by thermal cracking method. Then waste plastic fuels were blended with the diesel fuel at different ratios (10%, 20% and 50%). Fuel properties of each blend were measured in the Fuel Test Laboratory and engine performance and exhaust emission values of the blends were measured in the Diesel Engine Laboratory using a 4 cylinder commercial diesel engine.

Densities of municipal and medical waste plastic fuels are higher than diesel. Due to the higher densities of MUNWP and MEDWP in accordance with the diesel, blending with MUNWP and MEDWP were caused an increment in the density values. PP, PVC and PET structures of waste plastics are effectual for density values [11].

Cetane numbers of municipal and medical waste fuels are lower than diesel. Cetane numbers of blends can be decreased by mixing MUNWP and MEDWP with diesel. For waste plastic fuel-diesel blends, best Cetane number is MEDWP10.

One of the negative situations of waste plastic fuel is the high pour point. High pour point of a fuel can shows disquieting problems about transferring, storing and using in cold weather. MUNWP and MEDWP have high pour point. To add the MUNWP and MEDWP to the blends caused an increment in the pour point values. Pour points of waste plastic fuel-diesel blends are acceptable according to the EN 590 diesel standards.

Kinematic viscosities of municipal and medical waste plastic fuels are lower than diesel. It is observed that, MUNWP and MEDWP addition to diesel caused a decrease in the viscosity values. It shows that MUNWP and MEDWP can flow easier than diesel fuel.

There are no measurable differences observed for the flash point tests of MUNWP. Flash points of MEDWP fuel-diesel blends are lower than diesel. The experiments showed that MUNWP and MEDWP have lower calorific value than diesel. Therefore, MUNWP and MEDWP addition to diesel fuel caused a decrease in the calorific values. Brake power and brake torque values of MUNWP and MEDWP blends are lower than diesel fuel because of the lower calorific values of MUNWP and MEDWP compared to the diesel fuel. The decrease in Cetane number will have long ignition delay periods in a particular diesel engine.

Reduction and increment ratios of CO, CO₂ and NOₓ emissions of MUNWP and MEDWP blends compared to diesel fuel are shown in Table 3 and Table 4.

<table>
<thead>
<tr>
<th>Emissions</th>
<th>MUNWP 10</th>
<th>MUNWP 20</th>
<th>MUNWP 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>5.5% reduction</td>
<td>11.43% reduction</td>
<td>23.65% reduction</td>
</tr>
<tr>
<td>CO₂</td>
<td>2.22% reduction</td>
<td>6.47% reduction</td>
<td>13.3% reduction</td>
</tr>
<tr>
<td>NOₓ</td>
<td>4.3% increment</td>
<td>9.7% increment</td>
<td>20.3% increment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emissions</th>
<th>MEDWP 10</th>
<th>MEDWP 20</th>
<th>MEDWP 50</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>10.79% reduction</td>
<td>20.08% reduction</td>
<td>32.66% reduction</td>
</tr>
<tr>
<td>CO₂</td>
<td>1.34% reduction</td>
<td>7.45% reduction</td>
<td>14.75% reduction</td>
</tr>
<tr>
<td>NOₓ</td>
<td>6.6% increment</td>
<td>11% increment</td>
<td>20.7% increment</td>
</tr>
</tbody>
</table>

CO values of MUNWP and MEDWP blends are lower than diesel fuel because of their lower viscosity which increases atomization of fuel during the injection period. CO is a very toxic gas and CO can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues. At extremely high levels, CO can cause death. Exposure to CO can reduce the oxygen-carrying capacity of the blood. Carbon monoxide is a product of incomplete combustion of organic matter due to insufficient oxygen supply to enable complete oxidation to carbon dioxide (CO₂).

CO₂ values of MUNWP and MEDWP blends are also lower than diesel fuel because of lower ratio of Carbon atoms in the MUNWP and MEDWP fuels than diesel fuel. CO₂ is a greenhouse gas and the main pollutant for warming of the Earth. Rising CO₂ is therefore likely to have complex effects
on the growth and composition of natural plant communities in the future.

NO\textsubscript{X} values of MUNWP and MEDWP blends are higher than diesel fuel because of the better atomization creates higher combustion temperature in the engine cylinder. NO\textsubscript{X} emissions are only dependent on in-cylinder combustion temperature. NO\textsubscript{x} causes a wide variety of health and environmental impacts because of various compounds and derivatives in the family of nitrogen oxides. Increased nitrogen oxides deposition contributes to the formation of acid rain, which may cause extensive damage to the environment and human populations.

References: