PROCESSING OF MUNICIPAL WASTES AND PLASTICS INTO LIQUID FUELS – THE WtL TECHNOLOGIES

IZABELA SAMSON-BRĘK[1]

Automotive Industry Institute

Summary

At the current civilisation development stage, new problems are arising in connection with the availability of energy sources. At present, energy needs are chiefly satisfied by fossil fuels. However, fossil fuel resources are limited and may, according to forecasts of many scientists. be used up quite soon. Moreover, the process of obtaining energy from fossil fuels causes significant worsening of the state of environment and thus contributes to environmental degradation.

In the context of the above anxieties and threats, special interest is attracted to new energy carriers, which might constitute a supplement to fossil fuels and become an additional energy source and, in consequence, might improve national energy security and simultaneously help to improve environmental quality. As an energy source of this kind, municipal wastes, especially plastics, may be considered.

In this paper, two promising methods of making liquid fuels from municipal wastes and plastics, such as catalytic pressureless depolymerisation (KDV) and plasma waste disposal method, have been presented.

Keywords: municipal wastes, liquid fuels, plastics, WtL.

1. Introduction

At the current stage of civilisation development, new problems are arising in connection with the availability of energy sources. At present, energy needs are chiefly satisfied by fossil fuels [E, F]. Moreover, fossil fuel resources are limited and may be used up quite soon, according to forecasts of many scientists. What's more, the obtaining of energy from fossil fuels causes significant worsening of environmental quality and thus contributes to environmental degradation.

In the context of the above anxieties and threats, interest is attracted to new energy carriers, which might constitute a supplement to fossil fuels and become an additional energy

[1] Automotive Industry Institute, Renewable Energy Resources Department, 55 Jagiellońska Street, 03-301 Warsaw, e-mail: i.samson@pimot.org.pl, ph: + 48 22 777 72 14

source and, in consequence, might improve national energy security and simultaneously help to improve environmental quality. As one of the desired energy sources of this kind, municipal wastes, especially plastics, may be considered.

At present, using the technologies available in the market, the making of liquid fuels from plastics is not a cost-effective process; however, it provides a possibility of utilising a considerable quantity of wastes and thus it helps Poland to achieve the obligatory recycling level as required by the EU waste management regulations. By 2020, the recycling of paper, metals, plastics, and glass and the preparation of such materials for reuse is to be raised in Poland to a level of at least 50%; otherwise, Poland will have to pay heavy fines for every percentage point below the required level [A, B]. In addition to this, the number of municipal landfill sites in Poland will have to be reduced to 200 by 2014. This is a difficult task; nevertheless, it is feasible.

Two basic methods of making liquid fuels from plastics are distinguishable. In the first one, preselected and appropriately conditioned scrap plastics are heated to a temperature of 400÷500°C and then further processed. In the other one, wastes are mixed with oil of petroleum origin and then exposed to high temperatures. In both cases, appropriate catalysts must be used. As end products of these processes, liquid fuels are obtained.

This study was undertaken to analyse the possibilities of utilisation of municipal wastes, including scrap plastics, as raw materials for the production of liquid fuels and to highlight the resulting benefits for both the environmental quality and energy security.

2. Current situation regarding waste management in Poland

Poland is European Union's sixth largest waste-maker. In the recent years, the waste management system in Poland has been considerably modified. The grounds for these changes have been provided in particular by Council Directive 1999/31/EC on the landfill of waste [B] and Directive 2008/98/EC on waste (often referred to as "framework directive") [A]. These Directives impose an obligation on the EU member states to reduce the quantity of landfilled wastes and to manage wastes in compliance with the principles of sustainable development. Meeting the Directive requirements is very difficult for Poland because of insufficient availability of operating installations for waste recycling and for rendering wastes harmless, and only a small percentage of this may be turned into wastes that may be used as energy feedstock. Alas, landfilling is still one of the basic waste disposal methods in Poland.

In 2010, the total quantity of municipal wastes collected in Poland was 10 044 000 Mg, with 6 896 000 Mg (68.6%) of that being generated by households, according to the Report of the Implementation of the National Waste Management Plan in the period from 1st. January 2009 to 31st. December 2010. The quantity of co-mingled municipal wastes collected in the same time totalled 9 184 000 Mg, which included 2 392 000 Mg (26.04%) of wastes collected from the trade sector, small businesses, offices, and institutions, and 494 000 Mg (5.4%) of wastes collected from the municipal service sector. The percentage proportion between the wastes collected from urban and rural areas was 80.85% to 19.15%, respectively.

The quantities of the collected municipal wastes that were disposed of by landfilling, biological processing, and thermal processing were 7 369 000 Mg (73.37%), 609 000 (6.06%), and as little as 102 000 Mg (1.01%), respectively. The quantity of recyclable wastes sorted out from the co-mingled municipal wastes was 1 105 000 Mg (11.00%) [G].

The remaining municipal wastes were pre-sorted "at source" and collected selectively: in 2010, the quantity of municipal wastes collected selectively was 860 000 Mg, which made up 8.56% of all the municipal wastes collected. Among the pre-sorted solid wastes, the waste categories that made the largest parts were glass (25.1%), biodegradable wastes (21.0%), and paper inclusive of cardboard (19.8%). The biggest quantities of wastes were pre-sorted in Mazowieckie, Śląskie, and Dolnośląskie Voivodships, while Podlaskie, Opolskie, and Lubuskie Voivodships made the opposite end of this ranking list [G].

In comparison with the 2009 figures, the share of pre-sorted wastes in the whole stream of the wastes collected rose from 7.85% to 8.56%. Consistently, the percentage of landfilled wastes declined from 78.18% to 73.37% [G]. These data are not optimistic, but they indicate that the waste management system in Poland is changing and the changes show a favourable trend.

3. The KDV technology of production of diesel oil from wastes

The catalytic pressureless depolymerisation (KDV, which in German stands for "katalytische drucklose Verölung," i.e. chemical-catalytic pressureless conversion to oil) is an innovative and relatively environment-friendly technology of production of liquid fuels from wastes. This technology makes it possible to obtain diesel oil, kerosene, and petroleum from all the substrate types that contain hydrocarbons of both organic and mineral origin. The KDV technology has been invented by Dr Christian Koch, a German chemist and founder of the Alphakat GmbH company [Web 03].

The hydrocarbons contained in the feedstock are decomposed during circulation in the process installation under the influence of a catalyst suspended in the carrier oil at a temperature of 280÷340°C. The hydrocarbons contained in the input material are utilised to a degree of over 80%, which means that the process is highly efficient [Web 03]. The diesel oil vapours generated during the process are separated in a distillation column and the process residues that cannot be converted to diesel oil are removed. The end products of the process are liquid fuels and, additionally, biocomponents of the second generation (providing that biodegradable wastes are used as the feedstock).

The most important advantages of the process of catalytic conversion of wastes to oil are [Web 03]:

- Low process temperature, as the process takes place at a temperature of about 280°C;
- High processing efficiency (80%);

- High energy efficiency, because only about 10% of the fuel generated by the plant is used for in-plant purposes;
- Low quantity of wastes and pollutants emitted to the environment, chiefly thanks to the fact that the process takes place at low temperatures; the only wastes generated at the process are ash, which makes about 3% of the feedstock (this depends on the degree of contamination of the input material), CO_2 (10÷40%), and water.

The first KDV installations are already in service in Germany, Canada, Spain, and Mexico (Photo 1).

Photo 1. A fragment of the system operating in Hoyerswerda, Germany
Source: www.alphakatdiesel.pl/technologiakdv.html

4. Waste disposal by plasma processing

One of the promising methods of waste utilisation for energy generation is plasma processing, which makes it possible to produce energy feedstock in the form of synthesis gas. An unquestionable advantage of this technology is the possibility of recovering 90% of the feedstock energy as well as neutralisation and liquidation of the harmful components of wastes thanks to the application of very high temperatures.

4.1. Fundamentals of the plasma process

Plasma, which is the fourth state of matter, is an ionised substance whose state of aggregation resembles that of gas. The plasma consists of both charged and neutral particles; in the macroscopic scale, however, it is electrically neutral. In respect of the range of its temperatures, two plasma types may be distinguished [1]:

- Cold plasma (4 000÷30 000 K), which is generated in plasmatrons, i.e. devices used to generate plasma the temperature of which falls within the temperature ranges as mentioned above;
- Hot plasma (above 30 000 K), which occurs in the interior of stars or during nuclear explosions.

The obtaining of high-temperature plasma offers new possibilities of rendering wastes harmless, which are unavailable for traditional waste incineration technologies because wastes may be disposed of at very high temperatures, much higher than those achievable in ordinary furnaces, and this in turn translates into decomposition of harmful substances into simpler components that are safer for the man and the environment. Thanks to the high temperatures and no oxygen access, the plasma technology enables destruction of polychlorinated biphenyls (PCB), dichloro-diphenyl-trichloroethane (DDT), as well as lead, mercury, and cadmium compounds and prevents the formation of dioxins and furans [2].

The plasma technology finds application in the safe disposal of not only hazardous wastes such as contaminated soil, military wastes, or wastes with PCB or DDT contents but also municipal wastes and most organic wastes.

The essence of the neutralisation and liquidation of the active chemical substances contained in wastes lies in the use of plasma for the atomisation (i.e. decomposition of a homogenous substance into basic elements) and the oxidation and conversion of

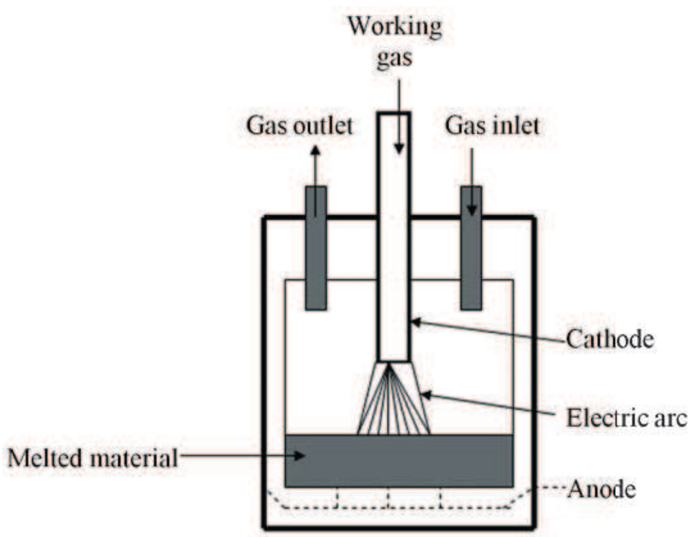

Fig. 1. Schematic diagram of the plasma reactor
Source: Author's study

process products into compounds of low activity level or inactive at all. If oxygen is fed to a reactor in which the processes of waste conversion and rendering the waste harmless take place (Fig. 1) then the waste may undergo complete oxidation and the end products of the process may have the form of sinter, slag, or vitrified substances. To obtain such an effect, stabilising substances are also added to the reactor because they fix and integrate the end products.

A very important product of the plasma process of rendering wastes harmless is syngas, i.e. synthesis gas. It is a combustible substance generated during the Fischer-Tropsch (F T) synthesis process. Such a process is a catalytic chemical reaction where hydrocarbons are obtained from a mixture of carbon monoxide and hydrogen. The F T synthesis process is run to produce fuels suitable for energy generation and transport purposes.

5. The plasma method of the 2nd generation and the "Green Power Plant" concept

The development of the plasma technology has enabled the production of syngas used inter alia for the environmentally sound generation of electric energy. In the "Green Power Plant" concept developed by General Plasma Sp. z o.o., whose operation is based on a technology named "Metoda Plazmowa II Generacji" (MPIIG = Plasma Method of the 2nd Generation), co-mingled wastes in the form of biomass, coal, hydrocarbons, as well as municipal and industrial wastes of any kind may be used as the substrate. A characteristic feature of this method is the fact that the wastes do not have to be sorted before being fed to the reactor.

In the Green Power Plant, about 97% of the feedstock energy is recovered [Web 01] in the form of syngas used for the generation of electric energy and heat, which are end products of the process.

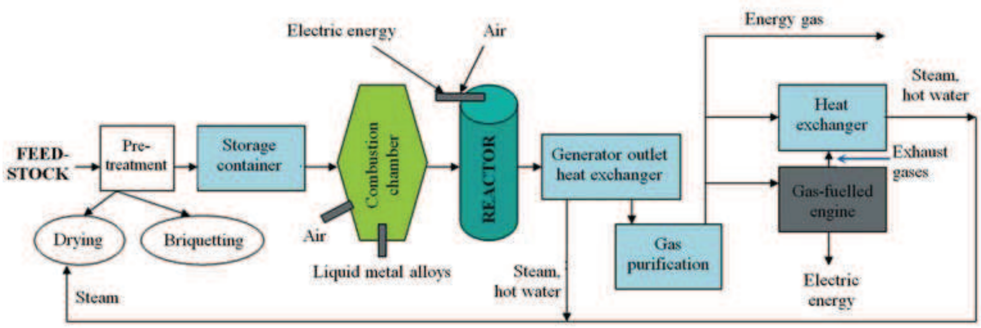

Fig. 2. Schematic diagram of the MPIIG installation
Source: Author's study; diagram based on http://www.generalplasma.com.pl

The MPIIG installation consists of the following major parts (Fig. 2) [Web 01]:
- Feedstock receiving and conditioning section;
- Thermal section with plasma generator;
- Reactor;
- Heat exchangers (to cool the gas);
- Gas purification system;
- Energy section (for electric or thermal energy generation).

The solid wastes used as the input material are fed to the feedstock conditioning and pre-treatment section where, depending on actual current needs, they are disintegrated (in the case of large-size objects used as the feedstock), compacted, or briquetted (when the feedstock particle size does not exceed 1 mm) and then sent to a gasifier. Liquid feedstock does not require any pre-treatment and is directly fed to the gasification chamber [Web 01].

The feedstock, either solid or liquid, is fed to the gasifier through a system of locks preventing the escape of pyrolysis gases that might contain harmful substances. After the chamber is filled with the substrate, gas of a temperature reaching 3 000÷5 000°C is supplied from the plasma generator to the gasifier to cause thermal decomposition of even the most toxic compounds [Web 01].

The gas formed during the pyrolysis process is directed from the reactor to heat exchangers, where it is cooled to a temperature of about 800°C. The heat carried by the gas is recovered in the heat exchange process and is then utilised for the generation of hot water.

Having been cooled the gas is sent to a purification system, which consists of a water scrubber (where gaseous impurities, chiefly hydrogen chloride and sulphur dioxide, are washed out), sorbent (active carbon, used for the removal of heavy metals), and an electrostatic filter. The syngas having been purified makes it possible to recover 60÷70% of the feedstock energy; another 20÷30% of the feedstock energy may be recovered as thermal energy. The combustion of 1 Nm^3 of the gaseous fuel obtained from the process produces 1 kWh of energy. At the final stage, the gas generated during the process is compressed and collected in storage tanks [Web 01].

6. The WtL (Waste-to-Liquid) technology in Poland

The first installations making it possible to produce liquid fuels from wastes are already in service in Poland. One of them is possessed by the Akropos company (Photo 2). Hydrocarbons are generated there in a two-module reactor in result of a process referred to as "thermo-catalytic transformation," with plastic wastes, chiefly polyolefins, being used as the substrate. Wastes generated by various industry branches may be used as the feedstock, e.g. [Web 02]:
- Empty containers used for various cleaning chemicals or cosmetics;
- Plastic films, disposable plastic bags of any kind and size, including carrier bags;

- Foodstuff packaging elements;
- Parts of household appliances;
- Parts of automotive industry products, e.g. bumpers or dashboards;
- Pieces of industrial textiles;
- Parts of radio, TV, and computer equipment;
- Parts of toys.

The process, which takes place under the impact of high temperatures (of up to about 500°C), without air access, at the atmospheric pressure, and in the presence of appropriate catalysts, results in decomposition (i.e. "depolymerisation") of plastics. An effect of such a chemical reaction is disintegration of polymers (polyolefins in this case) to monomers.

A characteristic feature of this technology is the possibility of mixing together, in any proportions, wastes with different polyolefin contents, including wet wastes (of up to 10% water content) and wastes contaminated with sand or glass, as well as the possibility of using unprocessed feedstock. Only large-size wastes, of size exceeding 100 cm^2, are subjected to pre-treatment by shredding [Web 02].

The feedstock is charged manually. The average processing rate of the installation is 400 000÷450 000 kg of wastes a month at a 24 hours/day operation mode, with the monthly output of the system ranging from 220 000 to 330 000 kg of the end product, i.e. liquid fuel components. The product is obtained in the form of thick paste of light yellow colour. It is traded under the name "Liquid fuel components, symbol PKWiU 24,66,32-90,00, CN 38,11" [Web 02]. The process efficiency is on a level of 62÷78%.

7. Conclusions

The issues pertaining to the use of renewable energy sources (RES), including the energy utilisation of wastes, are closely related to environmental protection and to the necessity of improving energy security through energy generation from unconventional sources. The energy utilisation of wastes makes it also possible for Poland to fulfil the obligations imposed on our country by the European Union regarding the share of RES in the total primary energy balance and a reduction of the landfilling of biodegradable municipal wastes.

The catalytic pressureless depolymerisation (KDV) is an innovative technology of production of liquid fuels from wastes. In this method, polymers are decomposed at low temperatures; thanks to this, no environmentally harmful substances such as dioxins or furans are formed. The quantity of solid wastes generated is significantly reduced as well. All these good points give grounds for the KDV technology to be claimed as being environment-friendly.

At the plasma technologies, on the other hand, high plasma temperatures reaching several thousand centigrade degrees cause all the harmful substances to be neutralised and fixed, with participation of stabilising agents, in slag, sinter, or vitrified substances. The

Photo 2. Installation for the production of liquid fuels by thermo-catalytic transformation, possessed by the Akropos company
Source: http://www.plastech.pl/wiadomosci/artykul_1698_1/Technologia-przetwarzania-odpadow--na-komponent-paliw-plynnych

end products of the plasma processes are electricity, heat, and syngas, which may be used for the production of motor fuels.

Both the KDV and plasma technologies are relatively expensive and require high investment expenditure for the construction of process installations as well as high costs of operation of the process facilities; in the case of plasma systems, high consumption of electric energy must also be taken into account. Nevertheless, both these technologies are considered promising and arouse increasing interest among potential investors both in Poland and abroad and they are likely to be counted in the future among the most important waste disposal and waste's energy recovery methods.

For both of them, the EIOER (Energy-Input-over-Energy-Return) indicator and then its rate of growth will have to be determined.

References

[1] KYĆ K.: *Analiza metod energetycznego wykorzystania odpadów* (*Analysis of methods of the energy utilisation of wastes*). The AGH University of Science and Technology, Faculty of Drilling, Oil, and Gas, the Cracow Conference of Young Scientists, Kraków, 2008.

[2] *Innowacyjne technologie unieszkodliwiania odpadów* (*Innovative waste disposal technologies*). Information for the Environment Protection, Natural Resources and Forestry Committee of the Sejm, Warszawa, 2008.

Legislative documents:

[A] Directive 2008/98/EC of 19 November 2008 on waste and repealing certain Directives.

[B] Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste.

[C] The Act on Wastes of 20 April 2001 (Dz. U. No. 62, item 628).

[D] Regulation of the Minister of the Environment of 27 September 2001 on the catalogue of wastes.

[E] Energy policy of Poland for the period until 2030, prepared by the Ministry of Economy, Warszawa, 2009.

[F] Forecasts of the fuel and energy demand in the period until 2030 (Appendix No. 2 to the Energy policy of Poland for the period until 2030), prepared by the Ministry of Economy, Warszawa, 2009.

[G] Report of the implementation of the National Waste Management Plan in the period from 1 January 2009 to 31 December 2010. Warszawa, December 2011.

Websites:

[Web-01] http://www.generalplasma.com.pl, visited in May 2012.

[Web-02] http://www.plastech.pl/wiadomosci/artykul_1698_2/Technologia-przetwarzania-odpadow-na-komponent-paliw-plynnych0, visited in May 2012.

[Web-03] http://www.alphakatdiesel.pl/technologiakdv.html, visited in May 2012.