

# Utilization of the Energy Potential of Waste from the Automotive Industry

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**Abstract.** Human life is inextricably linked to the generation of waste, whether at the municipal or industrial sphere. Waste is an important source of secondary raw materials and stored energy, which nowadays is advantageous to use. The most suitable way of waste recovery is its recycling and reuse. The share of waste that is unsuitable for recycling for various reasons is high, it currently exceeds the processing capacity of the Slovak Republic and is therefore deposited in landfills. The energy stored mainly in chemical bonds is therefore not used. The share of energy stored in this way is considerable, and its use would help not only in the field of rational waste management, but also in the field of power industry. The simplest way of energy recovery of waste is its direct combustion, more complex technologies are its gasification and pyrolysis. All technologies are called as Waste to Energy systems. Combustion of waste releases stored chemical energy, which is converted into heat, which is used for the production of electricity and heating. The products of gasification and pyrolysis are gaseous and liquid fuels that can be directly used in heat sources for the production of electricity and heat for heating, but also as an input material for the creation of high-grade fuels and for the chemical industry. The article deals with the conceptual design of a small facility for the recovery of waste, especially plastics, from the automotive industry and sorted municipal waste. The concept discusses the technical possibilities of preparing the input material, the technical ways of using it by gasification or pyrolysis, and the possibilities of using the resulting products of processing plastic waste. The assumptions for the design of a small waste recovery facility are verified on an experimental pyrolysis waste treatment device, the article contains the results of laboratory pyrolytic waste treatment and the properties of the resulting products.

## 1 Introduction

In every period of human society, waste was created, and we also know from archaeological finds about garbage dumps, where society stored things that they could no longer use or did not want to use. Even today, society creates waste, which society wants to get rid of. The most rational solution is to use waste as a secondary raw material. However, waste that can be reused as a raw material must meet certain criteria that cannot be met for a large part of

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the waste, and that is mainly the emphasis on species purity and purity from the point of view of contamination by other substances, that is, a large part of the waste can be used as an input raw material it cannot be used again in production. The second option is to use the waste as energy. Even according to the guidelines of the European Commission, waste that can be recycled or recovered for energy can be landfilled to a limited extent. Thus, even the European Commission encourages us that if it is not possible to reuse the waste, and if it can be used for energy, then it is necessary to use it for energy purposes. Plastics are one such waste that has a high energy value and is highly polluted, meaning that it is not suitable for reuse. The simplest way of energy recovery is incineration, where the energy from combustion is directly used in the form of heat, e.g. in cement plants or it will be used for heating and electricity production in incinerators, but the capacities of incinerators are limited in Slovakia and their location is not exactly the most suitable, which makes logistics difficult. An ecologically and energetically more appropriate solution is the use of new plastic waste processing technologies, e.g. gasification or pyrolysis, which transform this waste back into the starting raw material – gas and liquid phase, which can be used either directly as fuel or as input raw material for the petrochemical and chemical industry. The construction of such facilities in the territory of the Slovak Republic is not yet very widespread, the reason may be the financial difficulty or the almost non-existent market where the products of decomposition of plastic waste could be used. Existing operations, e.g. for the gasification and pyrolysis processing of plastic waste are rather pilot projects in Slovakia, they have limited capacity, they are unevenly distributed, which also implies the need to transport suitable waste over long distances from a wide area. Transporting waste over long distances can hardly be said to be economical and ecological. Large gasification and pyrolysis processing facilities are available in the world and on the market, which are investment-intensive and unsuitable for the conditions of the Slovak Republic. The starting point for this situation is the construction of smaller gasification and pyrolysis processing facilities, sized according to the amount of waste in the immediate vicinity, evenly distributed throughout the territory of the Slovak Republic, support for their construction by the state, e.g. appropriate legislation, subsidies, etc., and also the creation of a market for gasification or pyrolysis products - synthesis gas, oil, etc. Such smaller processing plants of non-recyclable plastic industrial and municipal waste could be located near larger sources of plastic waste, e.g. near processing facilities for discarded cars, or for associations of municipalities, or in areas for sorting municipal waste. Such an operation could be a modular system, e.g. placed in containers and could be adapted to specific requirements, types and quantities of processed waste. [1,2,3,6]

Gasification or pyrolysis processing of single-type sorted plastic waste (e.g. PET bottles, HDPE, LDPE, PP) is technologically manageable, the technology of processing mixed plastic waste, which can be contaminated with various impurities, such as waste from the automotive industry, is problematic. The disparity of this input material for energy recovery increases the technological complexity of the entire process. This waste is specific mainly due to its state (solid and liquid), species composition and various fractions (depending on the method of previous processing). Plastics, rubber, operating fluids (fuels, engine and transmission oils, cooling and brake fluids,...), leather, synthetic textiles, upholstery, etc. can be considered energetically usable waste from the automotive industry and car recycling. The largest share of energy-usable waste from scrapped cars is made up of plastics, which can generally be divided into polypropylene 35% of the total weight of plastics in a car wreck, polyurethane 20%, PVC 11%, ABS 10%, polyamide 9%, polyethylene 5% and other unspecified 10% . In the category of plastic waste, it is also possible to include the remains of cable scrap, they are made up of cable insulation, terminals, connectors, etc., they are mainly made of PVC and ABS and are no longer recycled, they are intended primarily for

energy recovery. The biggest problems in the energy recovery of plastics are with PVC, whose presence in the fuel is limited due to the resulting emissions (if PVC in the fuel is above 1%, an increased temperature in the combustion chamber and an increase in the residence time are necessary). The composition of the input fuel for the process of energy recovery of plastics is given by the technology of processing the car wreck. The crushed plastic portion after shredding is already very difficult to separate and this plastic portion is primarily intended for energy recovery, the input fuel has unspecified properties and composition. The most accurate chemical and physical properties and composition of the input fuel are achieved when the car wreck is completely dismantled. [2,3]

## 2 Pyrolysis

Pyrolysis is the heat treatment of waste substances in a pyrolysis furnace or reactor at a temperature of 250 to 1650 °C without air access, or with limited air access and at reduced atmospheric pressure. The result of pyrolysis decomposition is liquid substances (pyrolysis oil) and gaseous substances (pyrolysis gas).

The principle of this method of energy recovery of plastic waste is polymer degradation, which can take place with the participation of a catalyst, the reaction takes place in a closed reactor under the influence of heat. The reaction takes place either in the presence of a small amount of air or without the presence of an oxidizing agent, which is most often replaced by an inert gas, most often nitrogen and most often at normal atmospheric pressure. The batched mixture of plastic waste is depolymerized in the reactor, split into lower hydrocarbon chains (decomposition of long chains of plastic materials into a fluid mixture of saturated hydrocarbons). The waste plastic material is converted into gas, and by its subsequent cooling, it turns into oil fractions, the raw material from which it was originally made, and synthesis gas, which contains non-condensable molecules. By cooling the resulting fluid mixture of saturated hydrocarbons, the process of fractional distillation begins, i.e. the separation of individual oil fractions, when the plastic waste is converted back into the basic raw material. The resulting product of the process, which is called catalytic cracking, is a mixture of petroleum fractions, containing diesel, gasoline and oil components, paraffin, wax and other parts. [4,5]

Depolymerization most often takes place in the presence of a catalyst. When adding a catalyst, plastic waste acquires elasticity already at low temperatures (around 200 °C). The advantage of the catalytic depolymerization process at lower working temperatures is also the lower fuel consumption needed to heat the reactor. The catalyst is continuously added to the reactor, which ensures its continuous and stable activity and thus balanced working i.e. temperature conditions with a favorable effect on uniform product quality.

## 3 Input raw materials and output products

With the described technologies, it is possible to process various types of waste, municipal and industrial, biomass, plastics, old tires, etc. From plastic waste, waste polyolefins (polyalkenes) such as HDPE, LDPE and LLDPE are most often processed using the given technologies, i.e. polyethylenes of different specific weights and PP – polypropylene. The suitability of these polymers results from the fact that they are composed exclusively of carbon and hydrogen and their basic structural units are ethylene  $\text{CH}_2 = \text{CH}_2$  and propylene  $\text{CH}_3 - \text{CH} = \text{CH}_2$ .

Depolymerization using the methods described above produces synthesis gas from the input materials, which can be divided into condensable and non-condensable molecules by cooling (Table 1 shows an example of the composition of the synthesis gas depending on the input raw material). Depending on the input raw material, if it is plastic, after cooling it contains mostly liquid depolymerization products - crackers, which, depending on the conditions of the decomposition process, and especially depending on the height of the decomposition temperature, have an oily, waxy, or diesel character. These emerging products have a similar fractional composition to those produced primarily from petroleum. The remaining part after depolymerization is water and solid residue in the form of foreign residues from the original waste plastic raw material, in the form of e.g. metal residues, glass, stones, earth and other mechanical impurities. The resulting liquid and gaseous fractions do not contain a significant amount of halogens, sulfur, nitrogen or metals, as the original raw material does not contain them either. Therefore, from the point of view of chemical composition, there are practically only C1 to C5 hydrocarbons in the gas portion, and the output product of the entire technology is a mixture of liquid carbon and hydrogen, in a mass ratio of 86:14%, which are structurally predominantly unsaturated hydrocarbons without a significant content of aromatic compounds. The output product corresponds to the fractional composition of light heating oil, diesel fuel and wax, that is, raw materials that can be further processed in the petrochemical industry as a valuable raw material or can be directly used for the production of heat and electricity.

Application of the given technologies to other types of plastic waste, e.g. from the automotive industry is particularly problematic due to the diversity of the input material, which has a fundamental impact on the choice of depolymerization temperature, the length of the depolymerization period, the use of catalysts, the final product and residues after depolymerization.

**Table 1.** Example of synthesis gas composition depending on the type of input raw material

	H2 [%]	CH4 [%]	C2-C4 [%]	CO [%]	CO2 [%]	N2 [%]	Density [kg.Nm-3]	Calorific value [MJ.Nm-3]	Calorific value per ton of input raw material [kW/ton input]
biomass	15	26	3	35	17	4	1.10	17.10	2591
plastics	25	38	18	9	5	5	0.80	28.00	7778
tires	19	40	28	3.5	6.5	3	0.90	36.00	3333

## 4 Gasification and pyrolysis device

For gasification and pyrolysis, reactors are used, most often cylindrical in shape, depending on the amount of processed waste, they are constructed either as continuous or discontinuous. Both technological processes require the supply of a certain amount of heat, its amount depends on the working processes temperature, amount and type of processed waste. Heat to the process is supplied either by burning gaseous and liquid fuels or by electric heating. Heating with electric energy is realized directly, through an electric spiral, which can be placed in the feed screw. For safety reasons, heating by burning liquid or gaseous fuels in burners is most often

realized through an intermediate medium located in the double wall of the reactor. The reactor has thermal insulation due to the economy of operation. Reactor capacities range from several hundred kilograms to several tons of processed waste per hour. The retention time of the batch in the reactor and the operating parameters depend on the reactor design and the type of waste being processed, an example of operating parameters is shown in tab.2. The solid residue after the technological process is removed through the bottom of the reactor by a cooled screw conveyor. The amount of solid residue depends on the type of processed waste, technology and operating parameters.

**Table 2.** Examples of operating parameters of pyrolysis reactors

	Biomass <sup>1</sup>	Polymer plastics <sup>2</sup>	Tires
Working temperature	250 – 700 °C	650 – 800 °C	650 – 800 °C
Retention time	5 – 15 min	15 – 25 min	15 – 25 min
Amount of synthesis gas	15 – 80 %	60 – 95 %	30 – 60 %
Amount of synthetic oil (after cooling)	5 – 40 %	5 – 30 %	20 – 40 %
Solid residue <sup>3</sup>	15 – 90 %	2 – 30 %	35 – 45 %

<sup>1</sup> wood chip, agricultural dendromass, sawdust,...

<sup>2</sup> plastics, energetically significant components of municipal and industrial waste,

<sup>3</sup> changes depending on operating conditions (torrification / pyrolysis / high-temperature pyrolysis)

## 5 Preparation of raw material

The input raw material for the pyrolysis process was plastics that were obtained from a local scrap yard, where they were dismantled from car wrecks. Plastics were not selected according to purity, so some were with a surface treatment, e.g. varnishing and some without surface treatment. The material was sorted by type and was a mixture of plastics from the interior, bumpers, fenders and various covers from the engine compartment. These were mainly ABS, PP, PE and their approximate weight ratio, in which they are found in the car, was preserved. Plastics were selectively crushed (fig. 2) on a knife crusher (fig. 1). Subsequently, a mixture of crumbs was created according to mass representation. The crumb contained all the fractions that were created by crushing plastics in a knife crusher, i.e. from small particles of irregular shape to strips several centimeters long.



**Fig. 1.** Rotary grinding device



**Fig. 2.** The created mixture of plastic waste

## 6 Pyrolysis reactor

A small experimental pyrolysis reactor fig. 3, the main parts of which are a removable pyrolysis chamber, which is heated by a gas block burner and a condenser, where vapors generated in the pyrolysis chamber condense into pyrolysis oil. The non-condensed vapors coming out of the condenser are currently burned at the torch and in the future will be returned to the combustion process to heat the pyrolysis chamber, thereby reducing the energy requirements of the entire device. The proposed pyrolysis reactor works discontinuously, that is, after the end of the pyrolysis process, the chamber must be cleaned and filled again with a new charge. This reactor was designed so that we could carry out experimental measurements with different materials. During the tests, the entire pyrolysis process and also the entire reactor will be optimized to make the process as economical and efficient as possible considering the conditions.

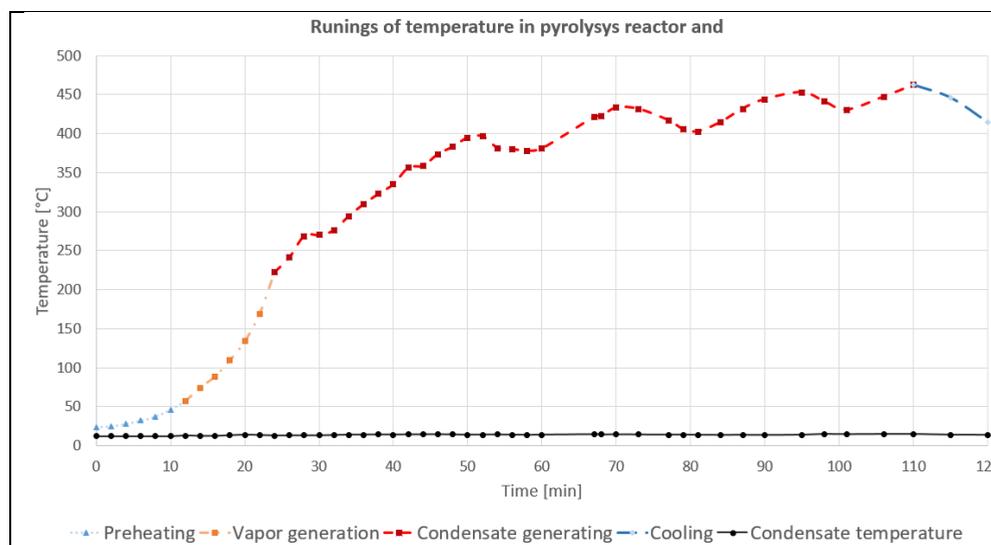


**Fig. 3.** Pyrolysis reactor (condenser is separate)

## 7 Experimental measurement

The laboratory discontinuous pyrolysis reactor (Fig. 3) was filled with a mixture of prepared plastic waste, one working batch weighed 3.5 to 4 kg. The reactor was filled in a cold state (at ambient temperature), the condensation exchanger was cooled to an average temperature of 13.5 °C. Different working temperatures in the range of 300 to 600 °C were chosen for pyrolysis. The course of working temperatures during the selected cycle of pyrolysis is shown in fig. 4. The pyrolysis process took place without added catalyst. In fig. 4, four phases of the pyrolysis process can be observed:

- Preheating phase – the working space is filled with an inert atmosphere, the temperature of the pyrolysis reactor and the charge rise from the ambient temperature, the phase is completed when the first vapors are released.
- Phase of vapor formation – the first vapors began to be released at a temperature of 62 °C, the supply of inert atmosphere from the pressure bottle was stopped, the start of the pyrolysis process no longer allows the entry of atmospheric oxygen, the vapors flow through the condensation exchanger but are non-condensable.
- Condensate formation phase – condensate began to form at a working temperature of 240 °C, at temperatures below 350 °C the condensate has an oily character, after complete cooling it has a waxy character with high viscosity, at higher working temperatures the viscosity of the product decreased.
- Cooling – after the end of the pyrolysis process (minimum amount of condensate formed), the reactor is cooled to ambient temperature so that it can be opened and solid residues can be removed.



**Fig. 4.** Working temperatures during pyrolysis

The resulting products of the pyrolysis processing of plastics were pyrolysis oil and gas, the by-product was a solid residue. Table 3 shows their representation in selected pyrolysis cycles. The average mass fraction of pyrolysis oil was 60.44%, pyrolysis gas 29.74% and solid residue 9.81%. Crude pyrolysis oil was made up of all condensable hydrocarbons that were formed during pyrolysis, it was represented by fractions with low viscosity (consisting of gasoline and diesel fractions, Fig. 5) to high viscosity fractions (oily and waxy, resembling

fuel oil, Fig. 6). The pyrolysis oil was dark brown to black in color, with a strong odor. The low-viscosity fractions were filtered (Fig. 7), the treated samples were subsequently weighed again. An example of the results of the sample processing after the pyrolysis process is shown in Table 4. The filtering took place at room temperature, which had an impact on the permeability of the sample through the filter, all the part of the sample that did not pass through the filter was included as waste from the process. The light fraction constituted about 40% of the weight of the obtained pyrolysis oil, the heavy about 33% and about 26.5% of the weight was removed by filtration. This amount of waste could be reduced if the filtering was carried out in a heated state of pyrolysis oil, the waste separated in this way is still highly flammable, which was confirmed by a combustion test.

After opening the pyrolysis reactor, the solid residue was removed, which, in addition to carbon, probably contains other components (metal pieces from the input material, heavy metals from surface coatings and adhesives, etc.). The solid residue can be used in the following pyrolysis cycle as a catalyst because it contains a high proportion of active carbon.

**Table 3.** Weights and percentage by weight in selected samples

	1. sample		2. sample		3. sample		4. sample	
	Weight [g]	%						
Pyrolysis oil	2140.0	59.3	2459.0	61.5	2118.4	60.1	2218.7	57.4
Pyrolysis gas	1139.8	31.6	1186.8	29.7	998.2	28.3	1196.6	31.0
Solid residue	329.1	9.1	345.2	8.9	406.2	11.5	446.8	11.60
batch	3608.9	100.0	4000.0	100.0	3522.8	100.0	3859.1	100.0

	5. sample		Average	
	Weight [g]	%	Weight [g]	%
Pyrolysis oil	2534.8	63.9	2534.8	63.9
Pyrolysis gas	1115.2	28.1	1115.2	28.1
Solid residue	317.0	8.0	317.0	8.0
batch	3967.0	100.0	3967.0	100.0



**Fig. 5.** Low-viscosity fractions after pyrolysis



**Fig. 6.** High-viscosity fractions after pyrolysis



**Fig.7.** Filtering samples

Results of partial chemical analysis:

After a partial chemical analysis, the following were mainly represented in the pyrolysis oil: ethylbenzene, hexene, styrene, heptene, benzene, cyclohexane, cyclooctatetraene and other chemicals.

## 8 Conclusion

In the future, pyrolytic processing of waste will play an important role in the use of waste, not only for direct energy use, but also as a source of input material for the production of noble fuels and lubricants, and also for the chemical industry for the re-production of new materials. Prospective research in this area shows that it is also possible to process mixed multi-species plastic waste, with an average gain of approximately 90% of the original mass usable for energy and other purposes (liquid and gaseous phase of pyrolysis products). The solid residue is suitable as a catalyst for the next cycle of pyrolysis, because of its increased content of harmful substances it is then suitable to be deposited in a landfill.

Such waste treatment requires further research in the field of the influence of the operating temperature of the pyrolysis reactor, the length of the residence time, the use of various catalysts to improve the economy of the operation of the pyrolysis reactor, and also in the field of pyrolysis oil and gas processing.

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