RECOVERY OF WASTE USING THE GASIFICATION AND OXIDATION OF SCRAP TIRES

FRANTISEK JANICEK[1], MARKUS GIEMZA[2], MILAN PERNY[1], VLADIMIR SALY[1]

[1] Slovak University of Technology Bratislava, Faculty of Electrical Engineering and Information Technology, Institute of Power and Applied Electrical Engineering, Bratislava, Slovak Republic

[2]Giemza Industrieanlagen, Asslar, Germany

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e-mail: milan.perny@stuba.sk

The investigation of the use of microwave gasification as a method that allows to obtain energy from end-of-life (ELTs) tires was subject of this study. The gasification of the waste was carried out within the laboratory microwave reactor HR – Lab, followed by the microwave-assisted oxidation of synthesis gas (syngas) which took place in a small microwave reactor – Microwave Oxidation System (MOS). Details of the experiment, such as power and temperature profile as a function of time and material charges distribution, are listed and explained. Analysis of gasification produced syngas in terms of composition and energy values was done also.

KEYWORDS

microwave reactor, renewable energy sources, pyrolysis, gasification, syngas

1 INTRODUCTION

Due to the legislation of the European Union (the EU) and its incorporation into the legislation of individual EU countries a big emphasis is put on the waste management and renewable energy [Nemethova 2014].

The great amount of waste is generated due to high living standard in many industrial countries. The nature of waste itself is changing partially due to the remarkable grow at the use of high-technologies and products [Nemethova 2010]. Therefore waste now contains an increasingly complex mix of materials, including precious metals and hazardous materials that are difficult to deal safely. The waste generation has a serious impact on the environment, causing pollution and greenhouse gas emissions, as well as significant losses of materials – a particular problem for the EU which is highly dependent on imported raw materials [European Union 2010, Janicek 2009].

A serious threat to the natural environment is also the increasing numbers of waste tires, of which more than 17 million tonnes are produced globally each year. Scrap tires are highly resistant to biodegradation, photochemical decomposition, chemical reagents and high temperatures, and have various chemical compositions. The restrictive EU legal regulations have led to solutions enabling rubber waste to be converted into energy or new polymer materials [Sienkiewicz 2012].

Fuels with high energy value can be obtained from carbonaceous feedstocks using gasification techniques. Techniques like gasification and pyrolysis can be applied to a wide range of waste materials ranging from agricultural crops over industrial waste, not excluding tires [Kubica 2008]. The resulting product of gasification is syngas composed of carbon monoxide and hydrogen. Gasification is a complex process. The quality (energy value) of syngas depends on the process parameters (temperature, pressure) and the amount of oxidizer [Abuadala 2010].

Gasification process using partial combustion of feedstocks can be carefully controlled by the amount of oxidizer which simultaneously influences the temperature of the process [Walawender 1985]. The process temperatures employed are usually higher than 650 °C [Janicek et al., 2009, Janicek et al., 2012].

The physical and chemical processes that take place in the combustion of crushed waste tires are similar as in case of other carbon feedstocks and wastes. The process includes drying, devolatilization, heat conduction, fissuring, shrinkage, and fragmentation of solid particles [Kumar 2004].

The most part of the available scientific papers focused on the waste tyre gasification is oriented on fluidized bed reactors in standard configuration [Portofino 2013], or various numerical simulations [Shabbar 2012] while data concerning other experimental designs are hardly found.

Due to specific effects of microwave irradiation and different interaction mechanisms with materials [Franek 2011], within this framework, the present study reports the results of an experimental survey of microwave assisted waste tyre gasification with the final goal of determining the influence of the temperature profile as a function of time and material charges distribution and the consequent impact on the composition and energy values of obtained syngas. The most essential benefits of microwave heating compared to conventional heating methods can be considered homogeneous heating of the whole structure, which results from the physical mechanisms of the interaction of the radiation on a molecular level [Sobhy 2010]. Quick start of heating and high dynamics of the process is another advantage of this approach. Finally, the experience with the application of microwaves in chemical and food industry proves that it is a nature, tested and economically acceptable technology.

2 METHODS AND EXPERIMENT

The aim of the experiments was to investigate the use of microwave gasification as a method of obtaining energy from end-of-life tires.

The overall experiment included:

- Microwave (MW) gasification of the scrap tires;
- Investigation of the syngas amount and composition in order to exploit it as a fuel for a combustion engine;
- Use of microwave reactor MOS as an exhaust gas cleaning system, in order to prevent emissions into the environment.

The experiments series with gasification of waste samples was carried out at the company Aton SA in Stradomia Wierzchnia (Poland).The microwave reactors used for these experiments were designed and constructed at this company. The series of tests was performed on the initiative of the company ASSA Ewenex Energy. The gasification of the waste was carried out at the laboratory microwave reactor HR - Lab whereas the microwave-assisted oxidation of syngas took place within the reactor MOS.

Microwave reactor HR is a continuous laboratory rotary kiln consisting of a ceramic drum located within a metal casing with microwave transmitters fixed to its walls. Powerful microwave generators are connected to these transmitters. The ceramic drum is transparent for microwave and does not absorb microwave also at high temperatures since ceramic shows very stable dielectric properties. The construction of HR microwave reactor is schematically shown in Fig.1.

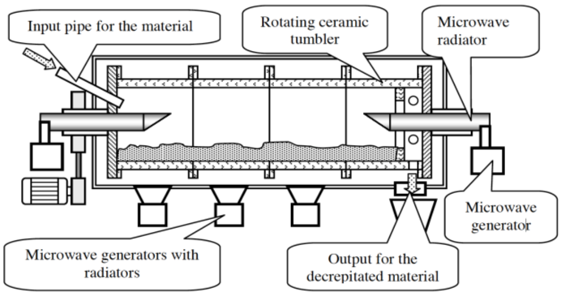

Figure 1. Scheme of microwave reactor Aton HR

Figure 2. MW reactor MOS with 3 sections

The investigated material was introduced into the interior of a slowly rotating ceramic drum. Since the ceramics of the rotating drum does not absorb microwaves, the microwave energy is transmitted directly into the material heating it to a high temperature. The feedstock is decomposed in the non-oxidative atmosphere (under lack of oxygen) into different gases and solid residues under high temperature. The temperature range in the reactor during the experiments was between 550 °C and 900 °C. The system was also equipped with a small microwave reactor – Microwave Oxidation System (MOS) consisting of three sections and had four microwave generators up to 3 kW each. Gas temperature measurement was performed by the N-type thermocouples. The system included the measurement of the syngas composition that was performed through two gas analyzers. One of them was checking the output gasses from reactor HR-Lab and second one the output gasses from reactor MOS as shown in Fig. 3.

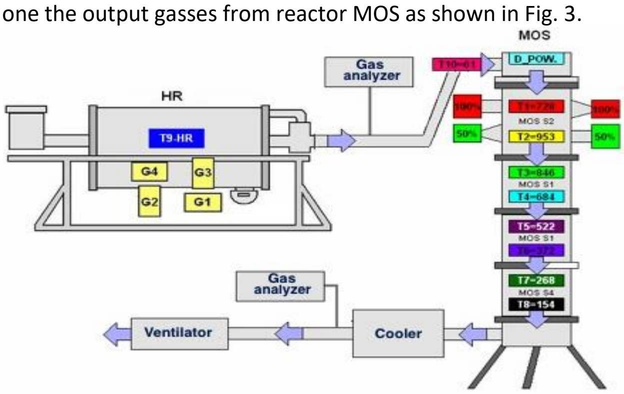

Figure 3. Setup for tires gasification experiment

The preliminary tests with the granulated scrap tires were performed in a laboratory muffle furnace (Fig. 4). The aim of the preliminary investigation was the determination of the gasification temperature and the temperature of spontaneous combustion of the gases, which occur in the scrap tires gasification.

Figure 4. Laboratory muffle furnace

2.1 *Details of the experiment*

The preliminary tests have clearly shown that the temperature of the most intense gasification and simultaneous ignition fluctuates around 600 °C. The Fig. 5 shows the feedstock before and after gasification.

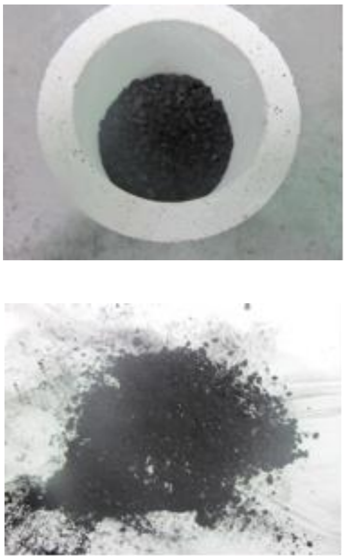

Figure 5. Scrap tires before and after the experiment

The temperature range of gasification in the microwave reactor was between 600 and 630 °C. The feedstock feeding into the reactor HR-Lab was carried out semi-continuously in the different batches, as shown in Fig. 6.

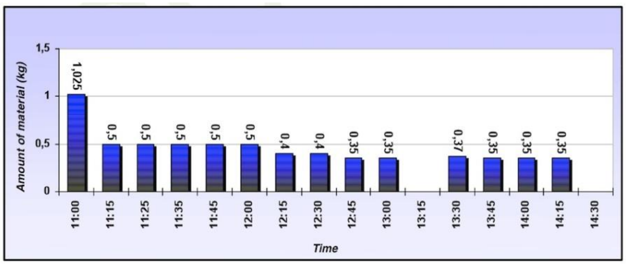

Figure 6. Feedstock charges distribution time of the HR-Lab

Fig. 7 shows the temperature course in the reactor HR-Lab and the power demand of the both reactors are illustrated in Fig. 8 and Fig. 9.

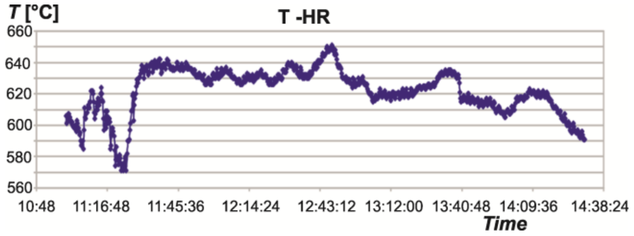

Figure 7. Temperature profile in MW reactor HR-Lab

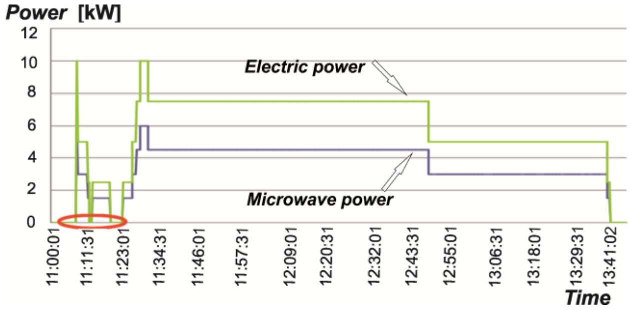

Figure 8. Power demand profile of the HR-Lab

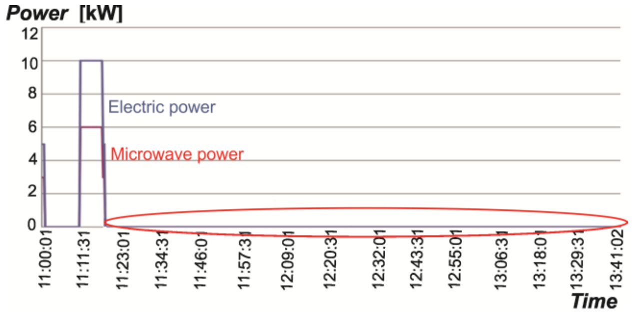

Figure 9. Power demand profile of the microwave reactor MOS

The microwave generators of the reactor HR-Lab with a total output of 12 kW had not required their full power at any point. Areas highlighted by red ellipse (Fig. 9) are those where the power consumption is reduced to zero. The temperature in the HR reactor was at about 600 °C as the first batch of feedstock was loaded. The initial stage of the gasification process was unstable likely due to the relative high amount of feedstock and air penetrated into the reactor, which had triggered an exothermic oxidation process. This had caused for a short time the temperature increase and the microwave power was automatically reduced. The power consumption had even dropped to zero and the temperature reduction at about 570 °C was observed. After the initial phase in the reactor the power consumption had increased briefly and stabile operation was achieved.

In the MOS reactor, where the oxidation of syngas took place, the microwave generators had worked only for a short time in the start-up phase, and were then switched off completely. The maximum temperature in the MOS reactor reached above 1300 °C and the temperature profile was quite stable without external energy input by microwaves (auto-thermal operation), what indicates a high energy content of the burnable components of syngas.

3 RESULT AND DISCUSSION

The syngas occurring during the gasification of scrap tyres is a mix of different gases with various properties (Tab. 1). At the first measurements the different components of syngas were detected, the second sequence was focused on the substances, which determine the heating value. Methane with the highest concentration followed by vaporized liquids like trichloroethylene and ethanol, which are also burnable, belongs to the most valuable components.

Component	Chemical symbols	Concen-tration [mg/m³]	Used method (applied standard)
Hydrogen sulfide	H_2S	744	WBJ-2/IB/171 wyd. 1 z dn. 31.12.2009r. (not accredited)
Methane	CH_4	178571	
Hydrogen chloride	HCl	35.8	PN-EN 1911-3:2003
Ethanol	C_2H_5OH	5627.4	WKJ-4/IB/95 wyd. 1 z dn. 06.11.2009r.
Buthanol	$C_4H_{10}O$	3.624	
Acetone	C_3H_6O	1.806	
Trichloroethylene	C_2HCl_3	6.068	
Butyl acetate	$C_6H_{12}O_2$	1.433	
Xylene	C_8H_{10}	29.03	
Benzene	C_6H_6	1521.5	
Toluene	$C_6H_5CH_3$	1826.4	
Ethylbenzene	C_8H_{10}	14.6	
Aliphatic hydrocarbons		Not detected	
Carbon monoxide	CO	2956.25	WBJ-2/IB/167 wyd. 1 z dn. 31.08.2009r
Nitrogen oxides	NO_x	125.05	
Sulphur dioxide	SO_2	3003.25	

Table 1. Syngas composition, which was generated at the gasification process of scrap tires

In the first measurements the different components of syngas were detected, the second sequence was focused on the substances, which determine the heating value.

The main substances of the syngas composition, which determine the resulting energy characteristics, are listed in Tab. 2 below. The syngas resulting from the microwave tire gasification consists partly of combustible components such as about 20 % methane, 20 % hydrogen, 5 % carbon monoxide and 1 % ethene and ethane. These results were measured in dry weight basis, dust and tar free gas, which correspond to the conditions of fuel for gas engines. Based on known composition of the natural gas the parameters like Lower Heating Value (LHV), Higher Heating Value (HHV), upper and lower Wobbe index as well as the density and the relative density in respect to air can be calculated using standard EN ISO 6976:2008 [PN-EN ISO 2008]. The computational algorithms of this standard allow the determination of energy content of other various gaseous fuels with some limitations in respect to nitrogen, carbon oxide and other compounds in the gas. Using these algorithms is possible without affecting of the correctness of the results, if the gas does not contain substantial amounts of heavy hydrocarbons [Holewa-Rataj 2015].

Component	Share [mole percent]
Ethane + Ethene	**1.194**
Propane + Propene	0.123
Carbon dioxide	3.071
Oxygen	0.000
Nitrogen	47.833
Methane	**21.035**
Carbon monoxide	**4.763**
Hydrogen	**20.115**

Table 2. Energetically relevant syngas components which was generated at the gasification process of scrap tyres

The content of carbon monoxide, hydrogen and methane and total amount of combustible components in syngas of 46 % is reflected in the LHV of 14.888 MJ.m^{-3} which is a relatively small value considering the high LHV of row material. The quantities of the LHV, HHV, upper and lower Wobbe index, density and the relative density are listed in Tab. 3.

Parameter of syngas	Unit	Calculated value
Higher heating value (HHV)	[MJ.m^{-3}]	16.492
Lower heating value (LHV)	[MJ.m^{-3}]	14.888
Density *(at STP, 0°C, 101.325 kPa)*	[kg.m^{-3}]	0.988
Relative density *(at STP - 0°C, 101.325 kPa)*	-	0.764
Upper Wobbe index W	[MJ.m^{-3}]	18.865
Lower Wobbe index W_i	[MJ.m^{-3}]	17.030

Table 3. Energetic values of syngas which was generated at the gasification process of scrap tyres

In general, the solid residues of the pyrolysis and gasification processes can contain various substances that diminish their quality. In this case however, due to the very high carbon content, the material would be suitable for further processing into a high end product, for example, activated carbon or as an aggregate for rubber-processing industry and many others. For this reason, the energy use of scrap tires by mentioned processes is doubtful from economic point of view.

Remarkable is the very high efficiency of VOC oxidation in the reactor MOS which was at almost 100 %. The MOS reactor had worked the most time in the auto-thermal modus without energy consumption for microwave generation.

4 CONCLUSIONS

The possibilities of recovering of scrap tires by microwave-assisted gasification were the objects of this study. Analysis of syngas composition from scrap tyres gasification and energy assessment of the obtained gases was carried out. The very high efficiency of VOC oxidation in the MOS reactor at almost 100 % was observed. The measured concentration of VOC behind MOS was virtually zero, independent on input values. The MOS had worked the most time in the auto-thermal modus without energy consumption for microwave generation. The high energy content of the solid residues from the gasification is an indication that these residues could be exploited for further energy recovery. The high carbon content in the gasification of scrap tires 99 % is as well as the HHV of the residues may be an indication that this method would able to obtain also other quality products in addition to gas fuels. The results of gasification were promising, however, in the waste treatment processes the cost issue is important.

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CONTACTS:

prof. Ing. Frantisek Janicek, Ph.D.
Ing. Milan Perny, Ph.D.
prof. Ing. Vladimir Saly, Ph.D.
Slovak University of Technology
Faculty of Electrical Engineering and Information Technology
Ilkovicova 3, 812 19 Bratislava, Slovak Republic,
Tel.: +421 2 602 91 746
e-mail: milan.perny@stuba.sk

Ing. Markus Giemza, PhD.
Giemza Industrieanlagen, Am Nickel 38
35614 Asslar, Deutschland,
Tel.: 06440 750901
e-mail: mgiemza@aol.com