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REFUSE-DERIVED FUEL ENERGY RECOVERY BY PLASMA TECHNOLOGY

ENERGETICKÉ ZHODNOCOVANIE RDF ODPADU PLAZMOVOU TECHNOLOGIOU

### Abstract

The paper reports the results of experiments focused upon high temperature gasification of waste with a significant proportion of combustibles. This is refuse-derived fuel (RDF) obtained by sorting the combustible components of communal waste. During the gasification of this waste in a plasma reactor (with a waste humidity of circa 24.9 %), when calculated per 1 kg of waste, syngas was obtained in an amount of 1.35 to 1.84 m<sup>3</sup>·kg<sup>-1</sup>. Apart from gas, the gasification process also creates slag of a glassy structure suitable for further use.

### Abstrakt

V príspevku sú uvedené výsledky z experimentu zameraného na vysokoteplotné splynovanie odpadu s významným podielom horľaviny. Ide o RDF odpad získaný triedením spáliteľných zložiek komunálneho odpadu. Zo splynovania tohto odpadu v plazmovom reaktore (s vlhkosťou odpadu cca 24,9 %), sa pri prepočte na 1 kg odpadu, získal syntézny plyn v množstve 1.35 až 1.84 m<sup>3</sup>·kg<sup>-1</sup>. Okrem plynu vzniká v procese splynovania aj troska sklovitej štruktúry, vhodná na ďalšie využitie.

## 1 INTRODUCTION

Waste disposal is becoming a worldwide environmental and economic problem of greater and greater dimensions [1]. The amount, diversity and possible toxicity together with growing heterogeneity of mixed waste complicate the options for its effective handling. Unsolved problems in waste management in any country therefore represent a time bomb, the consequences of which can barely be estimated.

Energy recovery of waste not used in recycling processes but which has properties suitable for use in energy applications is one of the possible as well as effective alternatives for its recovery and disposal.

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Apart from decreasing the volume of waste itself, thermal processes also partially address society's energy consumption from their own resources. A characteristic sign of thermal decomposition of primary and secondary fuel is the heating of material above the thermal stability level of the organic compounds present. The result of this process is the fission of high molecular substances with the simultaneous release of low molecular substances and even of elementary chemical elements [2-4].

The paper states the results obtained from plasma gasification of RDF, which not only resolves the problems linked to landfill, and this technology will also recover the energy content of the given type of waste.

## 2 MATERIALS AND TECHNOLOGY

The subject of the experiment focusing upon the high temperature gasification of waste with a high content of combustibles is refuse-derived fuel (RDF) obtained by sorting the combustible components of municipal waste. This, at first seemingly high quality mixture of selected components - municipal solid waste (MSW) - is compacted after separation and stored in packs before its transportation to places of final utilisation.

In the energy carrier market, RDF mainly finds its application as a supplementary fuel in cement plants. Burning it directly is problematic due to the high content of plastic fractions. However, this secondary fuel source can represent a valuable feedstock for technology transforming solid waste into gas fuel. The quality of RDF, its properties and content are significantly influenced by local and legislative requirements for waste recycling, the geographic position of the source of primary material entering the separation process, as well as the population's habits as consumers [4].

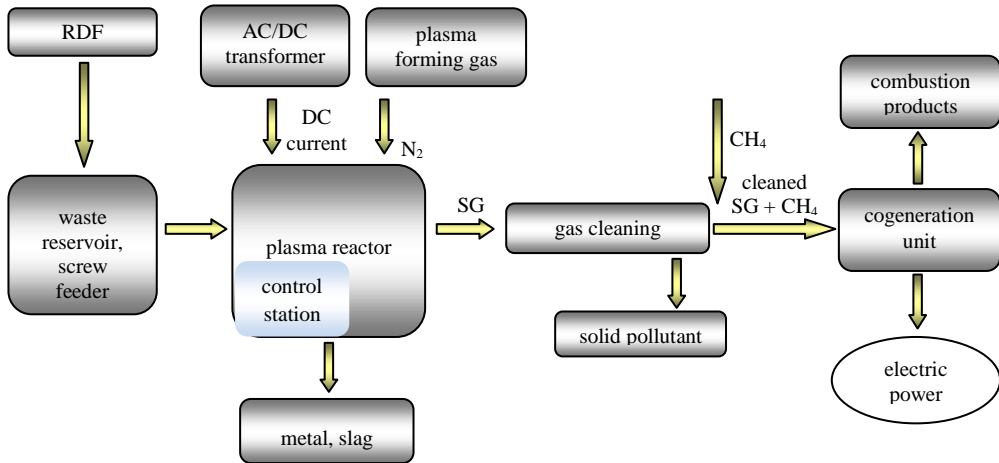
A sample of RDF, representing a very heterogenic, organic mixture with a humidity of circa 24.9 %, was used for experimental tests. The percentage share of combustibles and ashes contained in the sample, together with an elementary analysis of the sample, is shown in Tab. 1. The representation of slag-forming components, creating the majority proportion of ashes, created by annealing the waste sample at a temperature of 815 °C, is stated in Tab. 2. A diagram of RDF energy recovery process is shown on Fig. 1.

**Tab. 1** Content of the RDF batch

Batch content	Denomination	Batch content	
		for a dry sample (%)	for a moist sample (%)
C	% <sub>C</sub>	50.50	37.93
H	% <sub>H</sub>	6.16	4.63
O	% <sub>O</sub>	7.61	5.72
Cl	% <sub>Cl</sub>	0.44	0.33
S	% <sub>S</sub>	0.14	0.10
N	% <sub>N</sub>	0.07	0.05
Ash	% ash	35.08	26.34
Humidity	% humidity	0.00	24.90
Total		100.00	100.00

**Tab. 2** Ash content created in the annealing process of an RDF sample

Sample	Content of components (wt. %)				
	CaO	MgO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe
Ash	48.63	2.48	17.1	25.71	2.13



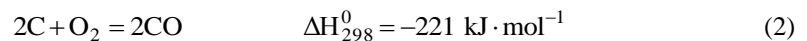
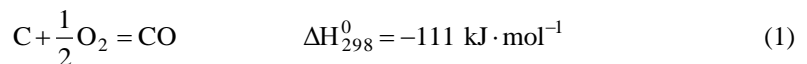
**Fig. 1** Diagram of RDF waste energy utilization process

This laboratory model for plasma gasification and melting waste consists of these five basic subsystems

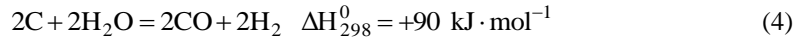
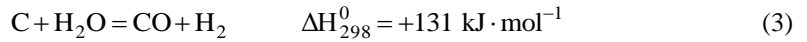
- **a plasma burner with transferred plasma arc.** The cathode in the system is created by a hollow, graphite electrode through which the plasma-forming gas (usually nitrogen) is passed to the electric arc,
- **a reservoir for batches and screw feeder equipment** with a fully automated control system,
- **a triple, three-phase transformer** connected to the triangle with an AC/DC thyristor. The role of three-phase transformers is to transform an alternative current into direct current, guaranteeing higher stability to maintain the arc discharge,
- **a system for cleaning syngas** for collecting solid pollutant present in the flow of produced syngas,
- **a control station** allowing operation of the plasma reactor in fully automated mode.

### 3 METHODOLOGY

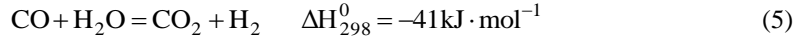
The gasification process may be characterised as a line of thermal-chemical sequences during which the conversion of a batch with high carbon content into gas products takes place. The conversion of pure carbon into carbon monoxide, using gas oxygen as the oxidising agent, is characterised by formulae of the partial oxidation of carbon - formulae (1) and (2) [5]



The combustion heat of such produced gas fluctuates around a level of 12.644 MJ·m<sup>-3</sup>. By adding water vapour to the process (from an external source or from the humidity contained in the batch), apart from a reaction of partial oxidation of carbon, there is also a gasification with steam reaction



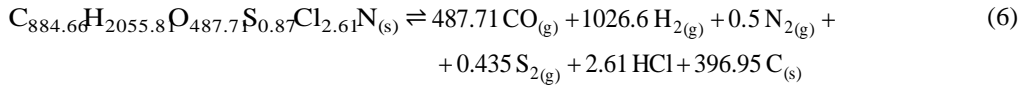
and a water-gas shift reaction



The total volume of produced oxides of the gas phase, as clear from formulae 1 to 5, is finally limited by the amount of oxidising agent introduced into the gasification process and released from the batch itself.

The result of gasification of the actual fuel will be a gas mixture which, apart from carbon monoxide and hydrogen, also contains other components such as  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{C}_n\text{H}_m$ ,  $\text{N}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{O}_2$ , etc. The gasification process itself is therefore more complex than in the case of gasifying pure carbon, and the total number of chemical-thermal sequences taking place in the conversion of fuel into gas products is more wide ranged.

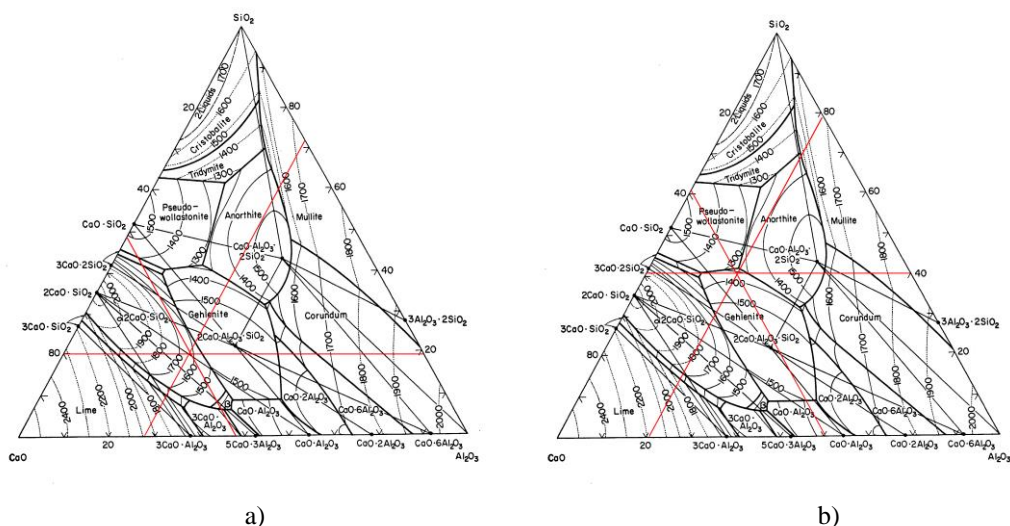
The decomposition of a batch into gas components whilst taking into consideration the calculated method stated in literature [6,7] in the pyrolysis conditions of processing can be, in accordance with the chemical reaction, expected to be in the shape



In accordance with reaction 6, apart from a gas mixture with a high  $\text{H}_2$  and  $\text{CO}$  content, there will also be elementary carbon ( $\text{C}_{(s)}$ ) in the form of soot created due to a deficit of oxygen in the batch. Introducing an external source of oxidising agent into the RDF gasification process will increase the carbon yield from the batch in the syngas in the form of carbon monoxide. There will be less soot created in the system, which will increase efficiency in the use of carbon for energy.

Oxides in ashes (Tab. 2) which are created by annealing the waste sample at  $815^\circ\text{C}$  are classified as dominant slag-forming oxides  $\text{CaO}$ ,  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$ . The percentage share of these components provides information on the theoretical melting point of slag generated in the gasification process. Under the assumption that the ash created only consists of the slag-forming components  $\text{CaO}$ ,  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  and they are calculated at 100 %, the melting point of slag produced during gasification is circa  $1670^\circ\text{C}$  (Fig. 2). Such a high melting point of slag is demanding in terms of energy and is unjustified for gasification of a batch. The melting point of formed slag may be reduced by adding suitable melting agents.

Due to the high content of the alkaline, calcium oxide, in the ashes, the most suitable melting agents for reducing the melting point of slag is an acidic melting agent. Therefore, silicon oxide is used as a melting agent during high temperature gasification and melting of an RDF batch with a humidity of 24.9 %. The ratio of the mixture of the batch to fine silicon sand (96 %  $\text{SiO}_2$ ) was stated at a level of 10:1.1 (RDF:melting agent). The stated ratio is based on theories about changes in the structure of the melting point of a pure batch with an added melting agent, stated using a ternary diagram of dominant slag-forming oxides (Fig. 2). Adding a melting agent in the stated ratio provides a decrease in the melting point of created slag to a value of circa  $1350^\circ\text{C}$  (Fig. 2). In terms of experimental experience and practical verification, this temperature is suitable for the refuse analysed.



**Fig. 2** (a) Ternary diagram CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> for RDF. (b) Ternary diagram CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> for RDF + fusing agent [8]

#### 4 RESULTS AND DISCUSSION

Plasma gasification of RDF was carried out at an average temperature of 1450 °C. The nitrogen flow through the graphite electrode was set at a volume of 9.2 l min<sup>-1</sup> (1<sup>st</sup> phase of gasification). 9.6 l·min<sup>-1</sup> of nitrogen was used for displacing technological openings. Displacement of seals is necessary around the place the graphite electrode enters the reaction chamber and around the dosing opening, in order to prevent unwanted leaks in the gasification process of the generated gas mixture. The stated volume of nitrogen is based on practical experience from research activities, providing reliable and secure operation in experiments using the laboratory plasma reactor.

The basic parameters describing the development of batch gasification and the amount of produced syngas per 1 kg of batch are summarised in Tab. 3. Gasification of refuse was carried out for two varying durations of experiments (two phases), varying dosing speeds and varying flows of plasma-forming gas.

**Tab. 3** Operational parameters for gasification of RDF

Operating parameters	Unit	Value (1 <sup>st</sup> phase)	Value (2 <sup>nd</sup> phase)
Temperature in the reaction chamber	°C	1450 – 1500	1450 – 1500
Time of experiment	min.	30	20
Batch weight	kg	2.4	2.4
Dosing speed	kg·min <sup>-1</sup>	0.08	0.12
Flow of plasma-forming gas (nitrogen)	m <sup>3</sup> ·min <sup>-1</sup>	0.0188	0.0092
Oxygen flow	m <sup>3</sup> ·min <sup>-1</sup>	0.008	0.008
Production of syngas per kg of a batch*	m <sup>3</sup> ·kg <sup>-1</sup>	1.350	1.803

\* parameter stated based on the balance of nitrogen

In the first phase of batch gasification, a syngas sample was taken (sample 1) and its content is given in Tab. 4. Then dosing of refuse was halted. The presence of chlorine, sulphur, heavy metals and other elements which are usually used in plastic as flame retardants (e.g. also bromine) was not analysed during gasification of RDF and, therefore, they are not discussed in this paper.

**Tab. 4** The results of chromatographic analysis of syngas obtained by gasification of RDF

Analysis type	Chromatographic analysis	
	sample 1 (vol. %)	sample 2 (vol. %)
CH <sub>4</sub>	0.82	0.26
H <sub>2</sub>	39.2	50.9
O <sub>2</sub>	0.04	0.03
N <sub>2</sub>	17.4	4.25
CO <sub>2</sub>	3.3	1.1
CO	39.1	43.5
C <sub>2</sub> H <sub>4</sub>	0.068	0.006
C <sub>2</sub> H <sub>6</sub>	0.003	0.001
C <sub>2</sub> H <sub>2</sub>	0.010	0.003
sum C <sub>3</sub> of hydrocarbons	0.007	0.005
sum C <sub>3</sub> of hydrocarbons	0.001	0.001
sum C <sub>3</sub> of hydrocarbons	0.001	0.001
HHV	9.52 MJ·m <sup>-3</sup>	11.10 MJ·m <sup>-3</sup>

Tempering the reaction chamber of the plasma reactor to a temperature of circa 1400 °C took place in the next hour. During this time, it is highly probable to expect the batch to dry in the reservoir.

Dosing the batch recommenced at a temperature of circa 1447 °C. By adding an oxidising agent in the form of pure oxygen at a volume of 8 l min<sup>-1</sup>, the temperature in the reaction chamber increased to a value of 1480 °C. Taking another sample of syngas was carried at in the 15th minute from starting to blow the oxidising agent into the process. The results of analysis of the syngas content are given in Tab. 4 (Sample No. 2).

The production of syngas per kg of processed batch in the first phase of gasification was stated via calculating the nitrogen balance to a value of 1.35 m<sup>3</sup>·kg<sup>-1</sup>. In the second phase of gasification, the production of syngas was stated using the same method and represented 1.84 m<sup>3</sup>·kg<sup>-1</sup>. The high percentage proportion of the two most dominant combustible components of syngas (i.e. H<sub>2</sub> and CO), representing 78 – 94 % of the overall syngas content (Tab. 4) predicts its possible energy use. The cleaning process must be carried out before the utilisation process [9].

The ratio of representation of CO<sub>2</sub> and O<sub>2</sub> components in the gas mixture created shows the defectiveness of the proposed gasification reaction sequences taking place in the gasification process. Dosing an oxidising agent with a flow of 8 l min<sup>-1</sup> into the plasma reactor reaction chamber is sufficient in terms of the content of syngas. Increasing the flow of oxidising agent will induce a decrease in the proportion of C<sub>(s)</sub> in the flow of syngas. On the other hand, it may cause an increase in the proportion of oxygen and carbon dioxide in the gas mixtures, which is unwelcome in terms of energy recovery.

The majority component of RDF ash is formed by oxides in which elements have a high affinity to oxygen. These were not reduced when the batch was processed, but created a separate oxidic liquid phase. A display of the solidified slag is shown on Fig. 3.



**Fig. 3** Solidified slag

This neutral "glassy" slag can be used, for example, in the building industry as filler for concrete.

## 5 CONCLUSIONS

In view of the environmental problems connected to storing and burning municipal waste, new methods for its disposal are being sought. One of the least investigated methods of thermal disposal of waste is its gasification in a plasma reactor. The stated gasification process analysed in this paper showed that, apart from an effective decrease in the volume and resolving the hygiene issue, this process also brings an opportunity for energy recovery from final products.

The first tests of gasification of RDF in a plasma reactor confirmed that gasification of the given type of waste using plasma technology is possible from a technological viewpoint; however, only further trials and tests will show the economic justification of this technology. The stated values of the production of syngas in the experiment are of a rather orientational nature. Their more accurate determination requires wider research in the semi-operational mode of the reactor.

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