

A CONCEPT OF THE GASIFICATION PLANT FOR SELECTED ORGANIC WASTE

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Abstract

It is observed that in the world economy the consumption of the natural resources increases which results in the growth of a stream of municipal and industrial waste. Both of these phenomena belong to the most important civilization problems. One of the potential directions of the waste management should be the recovery of energy from the combustible fraction. One of the possibilities to convert energy from waste into usable power is gasification, i.e. transformation of the municipal waste into syngas. The paper presents a concept of a gasification plant for gasification of selected organic waste. Tests were conducted for selected fractions from the stream of municipal waste. Simulation calculations of the gasification process were performed with the help of software ChemCAD 7.0.0.

Keywords: Waste; Management; Municipal; Plastics; Energy; Gasification; Conception.

1. INTRODUCTION

Today's waste management faces a great challenge. The consumptive lifestyle of nowadays societies (extract → produce → use → throw away) produces a growing stream of waste. This forces a search for new solutions for the waste management. Current purposes of waste management focus on taking maximum advantage of the waste potential. Reasonable use of the natural resources and assuring sustainable economy is a priority of the European legislature. Waste Framework Directive assumes elastic application of the recovery order: Reduce, Reuse, Recycle, Recover [1, 2, 3]. The main assumption of the Directive [3] is establishing laws which would promote the idea of „recycling society” that tries to limit the production of waste and use them as raw materials and sources of energy. By applying the above rule, we gradually approach the circular economy. The circular economy is an idea of producing and consuming energy, products or services in such a way as to limit demand for fuels, primary raw materials and water as well as land

and natural resources. Realization of such defined assumption requires above others segregation “at the source”, segregation and recycling of priority stream of waste, e.g. plastics, paper, metals, etc.

Growing amount of municipal waste is one of the most serious problems that the country members of the European Union face. Most of the municipal waste produced in the EU-28 countries is deposited in landfills [1–4].

For many years, Poland has been fighting with the problem of the municipal waste stream. The stream of municipal waste collected in 2016 in Poland is 7.5% larger than in 2015 and reaches 11.65 M Mg. Currently, there are average about 393 kg of collected municipal waste [2] per one Polish citizen comparing with an average of 483 kg [4–6] of municipal waste per one inhabitant of EU.

In EU countries, the recovery index of municipal waste and their reuse e.g. as secondary raw materials is improving. The recovery index in countries members of EU reached 47%.

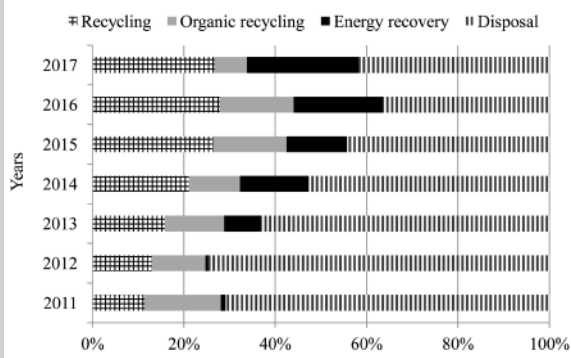


Figure 1.
Directions of municipal waste management in Poland [4–6]

In Poland, in 2016 disposal of municipal waste in landfills decreased (Fig. 1). Statistics Poland informs that 4.2 M Mg of the total amount of waste (approximately 36%) were directed to landfills, 7.8% (3.2 Mg) were recycled, 18.1% were destined for energy recovery and 16.2% of collected municipal waste underwent organic recycling (composting, fermentation) [4–6].

The direction of energetic use of a combustible fraction of the municipal waste has advantages because on the one hand it contributes to limiting the amount of waste at landfills and on the other hand it constitutes an alternative for depleting resources of conventional fuels [5–8].

2. METHODS OF ENERGY RECOVERY FROM THE WASTE

According to the current tendency of EU concerning directions of waste management, it is recommended to perform mechanical recycling or feedstock recycling. It needs to be noted that recycling of some waste, e.g. not uniform, mixed and contaminated is not always justified by the economy or environment. Recovery of energy is an alternative to recycling. It consists in combustion in the technology of combined heat and power generation. Recovery of energy from the municipal waste should constitute a method that is complementary to recycling and leads to the decrease of the stream of waste directed to landfills. From the energetic and economic point of view, some fractions selected from the stream of municipal waste constitute precious energetic material [8–13]. This management method has another advantage – it can cover all types of waste – especially non-uniform and contaminated for example with organic fraction [13–17].

Methods of thermal transformation of waste are represented by three basic processes: combustion, pyrolysis and gasification (Fig. 2). These processes are similar to a certain extent – the waste are heated to high temperatures. However, the basic difference lays in the amount of oxygen in the process:

- Combustion is performed in the presence of the excess oxygen and products non-combustible oxidation products: mainly carbon dioxide and steam.

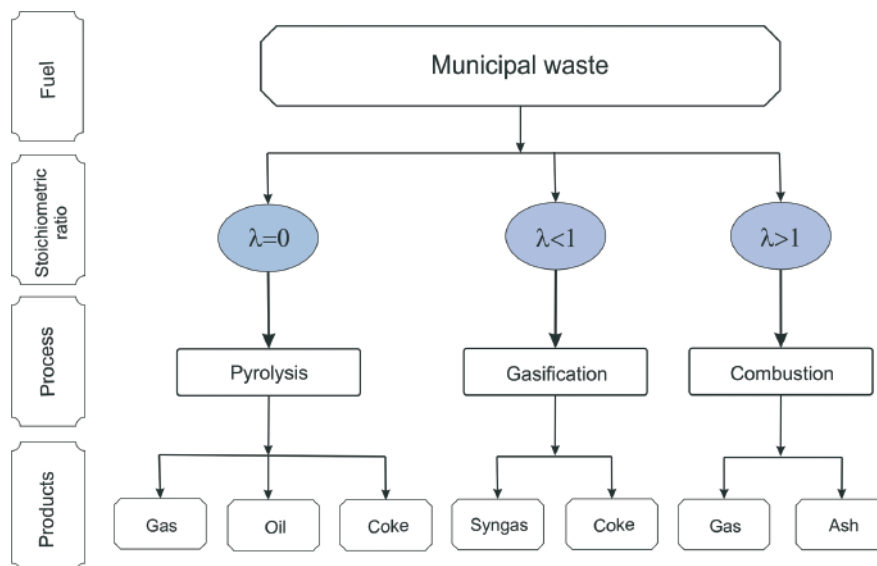


Figure 2.
Directions of thermal transformation of waste (own work)

- Gasification is performed with the reduced amount of oxygen directly supplied to the reactor, steam or carbon dioxide and generates combustible gas which contains hydrogen and carbon oxide.
- Pyrolysis occurs without the oxygen and leads to breaking polymer chains (depolymerisation) which results in the generation of light hydrocarbon fractions.

Another difference between the discussed thermal methods is the process temperature:

- Combustion is a high-temperature reaction which requires ignition, followed by the spontaneous sustenance of the process. The temperature obtained depends on the content of the combusted waste, excessive oxygen used and combustion technology.
- Gasification is conducted under high pressure in temperatures between 600°C and 1800°C, depending on the process used and expected substances in gas which is a product of the reaction.
- Pyrolysis is conducted mainly in temperatures that range from 350°C to 500°C.

The paper presents a concept of a plant for gasification of waste where organic waste are processed [18–21].

3. A DESIGN OF GASIFICATION PLANT FOR ORGANIC WASTE

The plant will consist of the following modules: a feeder, a reactor, a system for mechanical purifica-

tion of the gas, a system for chemical purification of the gas, pipelines of auxiliary utilities, automatic and control systems, supportive structures and access ways [22]. Flowchart of the plant with circulating fluidized bed is presented in drawing 3.

Gasification process will be carried out with parameters defined in Table 1.

Table 1.
Technical parameters of the plant for gasification of waste [22]

The type of deposit	Circulating fluidized bed
Process temperature, °C	1200
Working pressure, MPa	1.0–1.5
Reactor operating pressure, MPa	2.0
Gasification agent	steam/ O ₂ / CO ₂

Organic wastes will be collected in a waste bunker, from it they will be transported to the reactor through a tight dispenser and screw conveyor operating as an extruder. It is assumed that the waste will be continuously supplied to the gasification process. Such a solution assures constant operation of the bed and will not cause any temporal change to the composition of the produced gas.

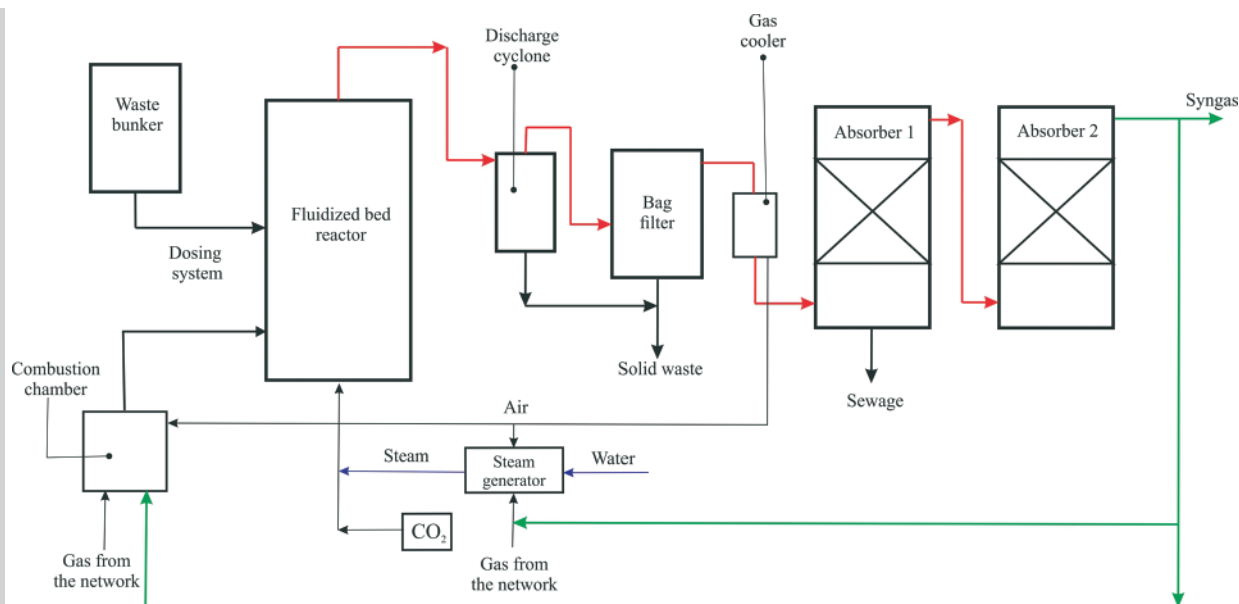


Figure 3.
Flowchart of the plant for gasification of waste [22]

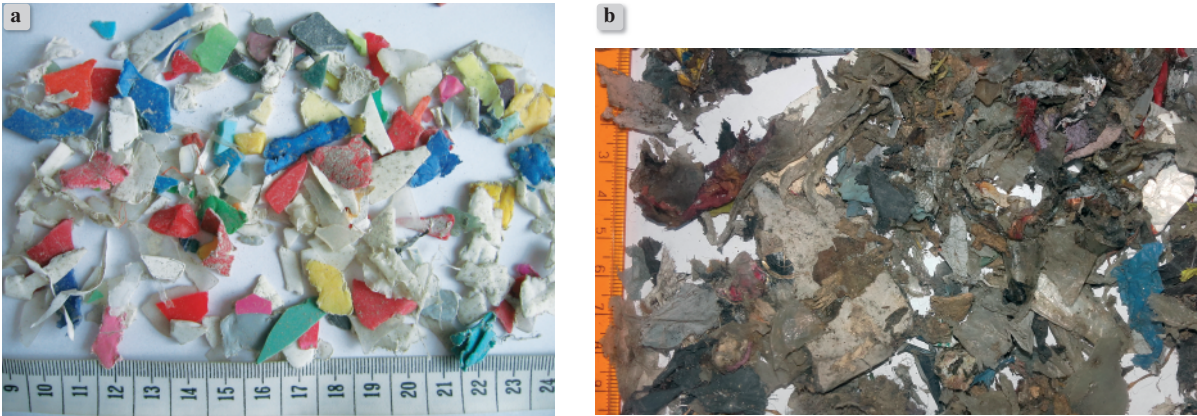


Figure 4.
Tested waste: (a) waste plastic (WP); (b) initially prepared municipal waste (MW) (performed by M. Czop)

The fluidized bed will be of circulating character, i.e. the speed of the gas supplied from the bottom through the grid will result in lifting lighter solid particles and moving them outside the reactor to the discharge cyclone, from where they will return to the reactor through the feeder and screw conveyor. They may be partially directed as solid waste. Heavier particles will float in the fluidized bed over the grid until they undergo reactions that result in the decrease of the weight and lifting to the circulating duct. Steam, oxygen and possibly carbon dioxide will be used as a gasification agent. Gasification agent will be heated to the temperature of about 250°C, which should positively affect the efficiency of the gasification process. Generated gas will leave from the plant at its top part, passing to the discharge cyclone where a separation of larger particles of dust drifting with the gas will take place. In the reactor, a few temperature and pressure sensors will be installed to monitor parameters in the generator during the gasification process [22].

Inside the plant, there will be a ceramic insert resistant to temperatures over 1300°C, which will enable conduction of the process with various parameters. The high temperature in the generator will enable an efficient decrease of tars. However, it should be considered that the energetic parameters of gas would decrease, too. After release from the discharge cyclone, gas will be directed into bag filter, where it will be mechanically cleaned from solid particles of 1µm and more. It is planned to take advantage of a bag filter used for clearing exhausts from power boilers since their construction is suitable both for working in high temperature and with combustible gases. Dust from bag filters will contain mainly biochar and ashes and will not undergo further processes – it will be treated as a waste.

After mechanical cleaning, gas will be cooled with the air cooler where the air used in the combustion process will be heated at the same time in the combustion chamber and steam generator. Cooled gas will be directed to chemical cleaning in absorber 1, where components dissolvable in water will be absorbed. Afterwards, in absorber 2 the remaining contaminations will be removed. Most of the cleaned gas (60–80%) will be received as a final product and directed for combustion in order to produce heating power or conveyed to engines for producing electrical power or stored for the use in chemical synthesis. The remains will be returned to the combustion chamber and steam generator and used as fuel.

Small amounts of biochar and ash generated in the process will be periodically removed from the discharge cyclone and bag filter and destined for further safe management process [22].

4. MATERIALS AND TEST METHODS

4.1. Characteristics of the processed waste

The following materials underwent physicochemical tests for the use in the gasification process:

- Waste plastics (WP), polyethene and polypropylene mix which comes from the selective collection of the municipal waste.
- Preliminarily prepared municipal waste i.e. (MW) segregated faction of highly calorific municipal waste.

4.2. Testing methodology

Physicochemical tests included the following determinations: Moisture content (M_T), fly ash (V), combustion heat (GCV), calorific value (NCV), elemen-

Table 2.
Standards for the physicochemical analysis

Title	Unit	Symbol	Standard
Determination of moisture content	%	MT	PN-Z-15008-02:1993
Determining combustion heat and calculating the calorific value	MJ/kg	GCV, NCV	PN-Z-15008-04:1993
Determination of ash content	%	A	PN-EN 15403:2011
Determination of fly ash by weighting	%	V	PN-EN 15402:2011
Determination of carbon and hydrogen	%	C, H	PN-Z-15008-05:1993
Determination of nitrogen with the Kjeldahl method	%	N	PN-G-04523:1992
Determination of sulfur with the Eschka method	%	S	PN-ISO 334:1997
Determination of chloride using the Eschka mixture	%	Cl	PN-ISO 587:2000

tal composition (C, H, S, N, Cl, O). Tests of energetic properties were performed in accordance with valid standards in the laboratory of the Faculty of Technologies and Installations for Waste Management at the Silesian University of Technology. All the tests were carried out in accordance with the standards presented in Table 2.

The obtained test results were introduced to software ChemCAD 7.0.0, where the calculation model was built and simulation calculations were made for the gasification system of selected waste fractions in the fluidized boiler with the circulating bed.

5. RESULTS AND DISCUSSION

Basic energetic properties and elemental composition of selected groups of waste are specified in tables 3 and 4. When analysing selected waste in the light of gasification in the fluidized bed, an emphasis was put on parameters which are important for the process: stable and uniform feed, stabilized grading, moisture content, content of ashes, carbon and hydrogen, calorific value: $NCV \geq 15$ MJ/kg (ar), content of chloride: $Cl \leq 1.50\%$ (d) and presence of other contaminations – up to 5.00%.

Tested plastic waste have low moisture content ($< 1.00\%$) and high calorific value (44 MJ/kg). They feature low ash content. ($< 1.00\%$). The content of fly particles reaches 99%.

Moisture content in the preliminarily prepared municipal waste equals 22.47%. The amount of ash is $< 10\%$. The content of fly particles in municipal waste reaches 79%. The calorific value in the operating state is 17 MJ/kg. Analysis of elemental composition proved that waste plastic consisted mainly of carbon and hydrogen. Tested waste plastic is characterized by long carbon chains $-C-C-C-$. A trace amount

Table 3.
Technical analysis of tested raw materials for the gasification process

Parameter	Symbol	Unit	WP	MW
Total moisture content	M_T	%	0.03	22.47
Combustible substances, Air Dried	X^d	%	99.10	92.44
Combustible substances, As Received	X^{ar}	%	99.07	71.67
Ash, Air Dried	A^d	%	0.86	7.56
Ash, As Received	A^{ar}	%	0.86	5.86
Volatile matter, Air Dried	V^d	%	99.13	79.06
Gross calorific value, Air Dried	GCV^d	MJ/kg	47.52	23.66
Gross calorific value, As Received	GCV^{ar}		47.50	18.29
Net calorific value, Air Dried	NCV^d	MJ/kg	44.38	22.62
Net calorific value, As Received	NCV^{ar}		44.36	16.97

of sulphur, nitrogen, chloride and oxygen was found coming from additives such as plasticizers or dyes.

The content of elemental carbon in the municipal waste reaches 43.29%. The content of chloride for the municipal waste air dried is 0.51% and is lower than the assumed value of 1.50%. Tested municipal waste have low sulphur content.

Table 4.
Elemental composition of selected waste

Parameter	Symbol	Unit	WP		MW	
			As Received	Air Dried	As Received	Air Dried
Carbon	C	%	85.28	85.31	34.63	43.29
Hydrogen	H	%	13.95	13.96	3.42	4.27
Sulphur	S	%	0.22	0.22	0.47	0.59
Nitrogen	N	%	0.29	0.29	0.88	1.10
Chlorine	Cl	%	0.19	0.19	0.41	0.51
Oxygen	O	%	0.00	0.00	31.86	39.64

Achieved test results for the analysed waste were introduced to the calculation model in ChemCAD 7.0.0. Obtained results of simulation calculations are presented in Tables 5 and 6.

Table 5.
The composition of synthesis gas from the process for WP

Components	Symbol	Unit	The composition of synthesis gas for WP
Hydrogen	H ₂	vol %	51.64
Carbon monoxide	CO		46.10
Nitrogen	N ₂		0.44
Steam	H ₂ O		0.78
Carbon dioxide	CO ₂		0.27
Argon	Ar		0.67
Sulfur dioxide	SO ₂	ppm	0.00
Hydrogen sulfide	H ₂ S		429
Ammonia	NH ₃		20
Hydrogen chloride	HCl		349
Gross calorific value	GCV	MJ/kg	19.03
Net calorific value	NCV	MJ/kg	17.44

Table 5 shows the composition of the received syngas for the raw material of waste plastic. It contains significant amounts of hydrogen and carbon oxide and its GCV equalled 19 MJ/kg. The content of nitrogen did not exceed 1.00%. The content of hydrogen sulphide in syngas amounted to 400 ppm, and content of hydrogen chloride to approximately 350 ppm.

Table 6.
The composition of synthesis gas from the process for MW

Components	Symbol	Unit	The composition of synthesis gas for WP
Hydrogen	H ₂	vol %	43.98
Carbon monoxide	CO		46.74
Nitrogen	N ₂		0.59
Steam	H ₂ O		5.81
Carbon dioxide	CO ₂		2.43
Sulfur dioxide	SO ₂		0.00
Hydrogen sulfide	H ₂ S	ppm	2500
Ammonia	NH ₃	ppm	23
Hydrogen chloride	HCl	ppm	988
Gross calorific value	GCV	MJ/kg	15.85
Net calorific value	NCV	MJ/kg	14.49

Physicochemical properties of the preliminarily prepared municipal waste forced modification of the input parameters: demand for oxygen decreased for the oxygen content in the municipal waste and demand for the steam decrease for the moisture content of the municipal waste. Table 5 presents the composition of syngas obtained for the municipal waste. It contained also significant amounts of hydrogen and carbon oxide and its GCV amounted to 16 MJ/kg. The content of nitrogen did not exceed 1%. The content of hydrogen sulphate reached 2500 ppm, and hydrogen nitrate about 1000 ppm.

6. CONCLUSION

Recovery of energy from the selected fractions of waste coming from the stream of municipal waste is favourable from the energetic and economic point of view. The process of gasification of waste is nowadays not popular although its technology is well known and described. Gasification may be a pro-ecological alternative for classic combustion of waste which still raises a social protest. Gasification of municipal waste is a pro-ecological investment as it concerns recovery of secondary raw materials – production of the process gas. Obtained syngas may be a source of relatively cheap raw material for many branches of the industry.

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