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Analysis of the Composition and Properties of Municipal Solid Waste and Their Use as Carbonaceous Feedstock in Underground Coal Gasification Process

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Analysis of the Composition and Properties of Municipal Solid Waste and Their Use as Carbonaceous Feedstock in Underground Coal Gasification Process

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Abstract. The development of new technological solutions in municipal solid waste management will reduce the adverse impact on the environment and human health. There are different methods of thermal disposal of municipal solid waste, such as incineration, pyrolysis,and gasification. The most effective and environmental method of thermal disposal is the gasification of solid wastes. This paper discusses the possibility of municipal solid waste gasification in underground coal gasification process and the prospects of gasification method following on from the analysis of the composition and properties of municipal solid waste. Municipal solid waste is a valuable carbonaceous feedstock that can be used in an underground coal gasification process to increase the life cycle of the underground gasifier, to produce additional volumes of synthesis gas, to stow the ash of municipal solid waste in mined-out space of underground gasifier. Operations of municipal solid waste preparation need to improve the efficiency of the gasification process. A considerable volume of municipal solid waste is an alternative carbonaceous resource, which can provide the needs of power and chemical industry for synthesis gas.

1. Introduction

Currently, the world generates about 1.3 billion tonnes of municipal solid wastes (MSW) per year. Every year, the volume of solid waste in the world is growing. By 2025, this will likely increase to 2.2 billion tonnes of MSW per year. Globally, waste volumes are increasing quickly – even faster than the rate of urbanization. Similar to thelevel of urbanization and growth ofthe gross domestic product, the rates of MSW generation are fastest in China, other parts of East Asia and parts of Eastern Europe and the Middle East [1].

The volume of MSW in Russia has been increasing in recent years as well.In 2016 approximately 52.4 million tonnes (268.8 million m^3) of MSW was generated by the country. 3.9 million tons (23.9 million m^3) of which gets to the processing, 1.0 million tons (6.4 million m^3) including waste at incineration plants is detoxified, and 47.6 million tons (238.5 million m^3), accounting for 88.7% of the total export of MSW, is sent to landfills and dumps [2].

At present, Russia has more than 14,700 authorized waste disposal sites, which occupy about 4 million hectares [2]. The remaining capacity of landfills is estimated between 30 and 35 percent. For the disposal of MSW annually about 400,000 hectares has been allocated.The current rate at which new capacity is created does not ensure the ability to process projected volumes [3].

Landfills are not only required to allocate the land from the economic turnover, but they pollute the atmosphere, surface soil and underground water, and have a negative impact on flora and fauna.

There are different methods of waste disposal. Fig. 1 shows the current annual global MSW disposal.

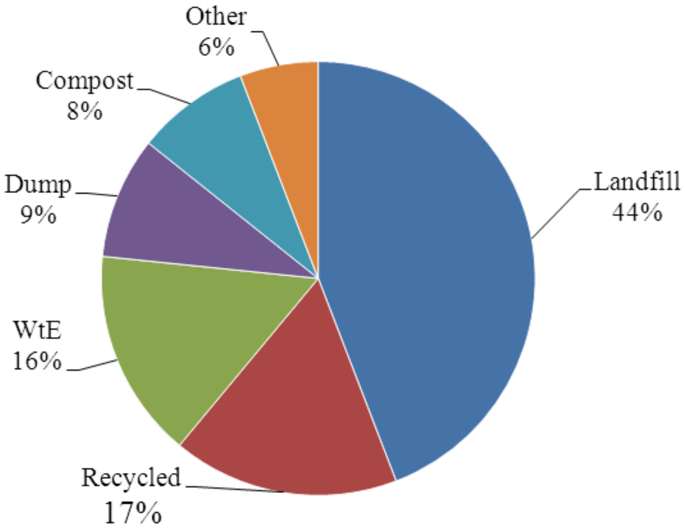

Figure 1. Total MSW disposed of worldwide.

The most common methods of MSW disposal in high-income countries are the landfilling and thermal treatment of solid waste.

Currently, MSW are regarded as valuable renewable resources, most of which find disposal into landfills and dumps in Russia. Interest in waste as renewable energy resources is increasing all over the world. There are different methods of thermal treatment of solid waste in the world. One of the prospective methods of thermal treatment is the solid waste gasification in the underground coal gasification process.

Solid waste gasification produces synthesis gas, which can be used to generate heat energy (specifically through the method ofwaste gases heat recovery from underground gas generator [4]), electricity (including the use of theOrganic Rankine Cycle (ORC) [5]) and to produce of synthetic liquid fuels, methanol, dimethyl ether and other chemical products in the chemical industry.

Gasification of solid waste in underground coal gasification process provides:

– to increase the life cycle of the underground gasifier;

– to increase the volume of produced syngas for the period of operation of the underground gasifier;

– utilization ofthe ash of solid waste in the underground gasifier;

– to stow the ash of solid waste in mined-out space of underground gasifier.

2. Composition and properties of municipal solid waste

The percentage of the morphological composition of MSW is approximate. It is characterized by significant seasonal fluctuations with notable differences in multiple cities and countries. Global MSW composition in 2009 is shown in fig. 2 [1].

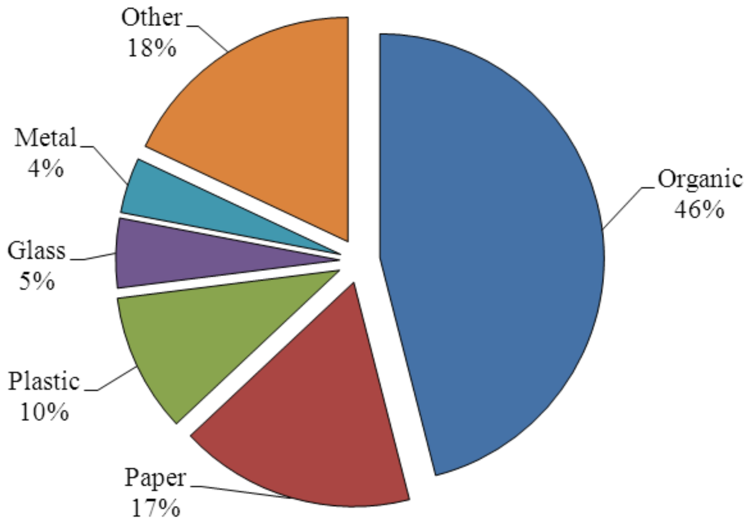

Figure 2. Global solid waste composition.

Types of solid waste and their sources are shown in table 1.

Table 1. Types of solid waste and their sources [1].

Type	Sources
Organic	Food scraps, yard (leaves, grass, brush) waste, wood, process residues
Paper	Paper scraps, cardboard, newspapers, magazines, bags, boxes, wrapping paper, telephone books, shredded paper, and paper beverage cups. Strictly speaking,paper is organic,but unless it is contaminated by food residues, itis not classified as organic
Plastic	Bottles, packaging, containers, bags, lids, cups
Glass	Bottles, broken glassware, light bulbs, colored glass
Metal	Cans, foil, tins, non-hazardous aerosol cans, appliances (white goods), railings, bicycles
Other	Textiles, leather, rubber, multi-laminates, e-waste, appliances, ash, other inert materials

MSW can be considered as unconventional energy resources, consisting of the organic part, water,and the inorganic part is similar to traditional fuels:

– Organic(combustible)part–32.6-72.0%;
– Moisture, W_t – 12.0-50.0%;
– Inorganic(mineral)part,A_d–16.0-17.4%.

Gasification of solid waste is the process of decomposition of the organic part at high temperatures. Organic part is a significant proportion of solid waste and is of interest for gasification.

The approximate elemental composition and main properties of solid waste components are shown in table 2. The calorific value, volatiles,and moisture are essential properties of solid waste.

Anessentialfactorforthesolidwastegasificationintheundergroundgasifieris thesizeofthecarbonaceousfeedstockcomponentsthatarefedtotheunderground gasifier. Fractional composition is the percentage ratio of the components of differentsizes.Theapproximatefractionalcompositionofsolidwastecomponentsis shown in table3.

Table 2. The approximate elemental composition and main properties of solid waste components.

Components	The approximate elemental composition, %							Volatiles (dry matter), %	Low calorific value, MJ/kg
	C	H	O	N	S	A^d	W_t		
Paper	27.7	3.7	28.3	0.16	0.14	15.0	25.0	79.0	9.49
Wood	40.5	4.8	33.8	0.1	0.1	0.8	20.0	67.9	14.46
Textiles	40.4	4.9	23.2	3.4	0.1	8.0	20.0	84.3	15.72
Plastic	55.1	7.6	17.5	0.9	0.3	10.6	8.0	79.0	23.37
Leather, rubber	65.0	5.0	12.6	0.2	0.6	11.6	5.0	49.0	25.79
Food scraps	12.6	1.8	8.0	0.95	0.15	4.5	72.0	65.2	3.43

Table 3. The approximate elemental composition and main properties of solid waste components.

Components	The approximate fractional composition, %				
	more than 250 mm	250 – 150 mm	150 – 100 mm	100 – 50 mm	less than 50 mm
Paper	3 – 8	9 – 11	9 – 11	7 – 9	2 – 5
Wood	0.5 – 1	0 – 0.5	0 – 0.5	0.5 – 1	0 – 0.5
Textiles	0.2 – 1.3	1 – 1.5	0.5 – 1	0.3 – 1.8	0 – 0.6
Plastic	0 – 0.2	0.3 – 0.8	0.2 – 0.5	0.2 – 0.5	0.2 – 0.5
Leather, rubber	–	0 – 1	0.5 – 2	0.5 – 1.5	0 – 0.3
Food scraps	–	0 – 1	2 – 10	7 – 13	17 – 22

3. Preparation of municipal solid waste for gasification in underground gasifier

MSW is not suitable for underground gasification because waste has a heterogeneous composition after formation. To ensure gasification of MSW in the underground gasifier, waste must be prepared. Preparing of solid waste for the underground gasification consists of the following steps: separation, drying,and milling.

3.1. Waste separation

Only the organic part of solid waste is of interest for the gasification, and, therefore, it is necessary to enrich the solid waste for converting it into the carbonaceous feedstock with homogeneous and stable composition. Solid waste must be sorted to remove inorganic components, such as glass, metal, or stone. It is also necessary to remove polymers because they are converted into harmful substances such as dioxins and furans (carcinogen) during thermal disposal. Waste separation prepares the desired composition of MSW, which is suitable for gasification in underground gasifier during underground coal gasification process.

3.2. Waste drying

The next step of solid waste enrichment is drying that ensures the extraction of excess moisture. Drying of MSW prepares carbonaceous feedstock to the desired level of humidity. As a result of separation and drying, the percentage of carbon in the waste increases substantially.

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3.3. Waste milling

The gas flow in the channel of underground gasifier provides gasification of carbonaceous feedstock in suspension state, but it requires milling the waste to prepare a homogeneous mass with high volatility, that is, the possibility to supply the carbonaceous feedstock into the underground gasifier and provide a better chemical reaction with an oxidant.

4. Feeding of a carbonaceous feedstock into the underground gasifier

The gasification of solid waste in underground gasifier requires the use of a carbonaceous feedstock which hashomogeneous fractional composition, providing the volatility of components by technological parameters of injected gas in the piping of a suitable size.

After separation, drying and milling, the carbonaceous feedstock is fed into the underground gasifier through injection well via jet device which is integrated into the injection system. Injection of a carbonaceous feedstock into the underground gasifier through pipes is based on the principles of pneumatic pipeline.

The main parameter for the calculation of the pneumatic pipeline is the physical properties of the carbonaceous feedstock. It is necessary to consider the size of feedstock components, specific weight, humidity, suspension and so on. Other parameters for the calculation are the pneumatic system performance and transport conditions.

To ensure the supply of carbonaceous feedstock into the underground gasifier, it is necessary to determine the following parameters: size of the carbonaceous feedstock components, the concentration of fuel mixture, feed rate of injected gas, pipe diameter and pipe configuration. These parameters are variable and are calculated under specifictechnical parameters of underground gasification.

5. Syngas production

Production of synthesis gas by the gasification of a carbonaceous feedstock in the underground gasifier is due to the chemical reactions in the gasification channel. The importance of this process is the heterogeneous interactions of gasifying components with carbon of coal and additional carbonaceous feedstock. The rate of heterogeneous reactions is mainly determined by the reacting surface. After injecting of additional carbonaceous feedstock, the contact surface of solid and gas phases is increased, and then the speed of processes is increased.

From the viewpoint of life cycle of the gasifier, to produce a unit of syngas volume per unit of time is less coal gasified due to the carbon of additional carbonaceous feedstock is reacted with the gasifying agent of injected gas in the gasification channel.

The main reactions of carbonaceous feedstock gasification are as follows:

Combustion reactions:

$$C + O_2 \rightarrow CO_2 - 393\ kJ/mol \quad (1)$$

$$\mathrm{2C + O_2 \rightarrow 2CO - 111\ kJ/mol} \quad (2)$$

$$\mathrm{2CO + O_2 \rightarrow 2CO_2 - 282\ kJ/mol} \quad (3)$$

$$\mathrm{2H_2 + O_2 \rightarrow 2H_2O - 242\ kJ/mol} \quad (4)$$

Boudouard reaction:

$$\mathrm{C + CO_2 \rightarrow 2CO + 172\ kJ/mol} \quad (5)$$

Water-gas reaction:

$$\mathrm{C + H_2O \rightarrow CO + H_2 + 131\ kJ/mol} \quad (6)$$

Hydrogasification reaction:

$$\mathrm{C + 2H_2 \rightarrow CH_4 - 75\ kJ/mol} \quad (7)$$

Water-gas shift reaction:

$$CO + H_2O \rightarrow CO_2 + H_2 - 41\ kJ/mol \quad (8)$$

Steam methane reforming reaction:

$$\mathrm{CH_4 + H_2O \rightarrow CO + 3H_2 + 206\ kJ/mol} \quad (9)$$

6. Conclusion

Based on the analysis of the composition and properties of the MSW, the article discusses about the possibility of practical use of solid waste as additional carbonaceous feedstock in the underground coal gasification process. Possibility of solid waste gasification in the underground gasifier can only be implemented with the necessary preparation. Gasification of solid waste in the underground gasifier increases the life cycle of the underground gasifier, increases the volume of produced synthesis gas for the period of operation of the gasifier, provides ash disposal of solid waste in the underground gasifier and stows into the mined-out space of underground gasifier.

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