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Motor Fuels and Energy – Producing Fuels Generation Based on the Processing of Municipal Solid Waste Organic Components

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ABSTRACT

Municipal solid waste management and its disposal are considered one of the major challenges facing the urban communities around the world. Effective solid waste treatment involves a variety of approaches, treatment technologies and concepts to ensure the protection of public health and the environment. Waste landfill is the method most commonly used worldwide, despite all the significant environmental, health and economic consequences. Thus, alternative methods such as the municipal solid waste pretreatment, fermentation, ethanol fermentation and anaerobic fermentation have been the focus of heightened attention. Using these methods, an alcohol-containing liquid was obtained from 1.5 kg of the organic fraction of municipal solid waste (OFMSW), which had an ethanol percentage of 97.45%. Consequently, if properly managed and used, municipal solid waste can be a viable source of energy rather than a source of pollution.

Keywords: municipal solid waste, bioethanol, fermentation, ethanol fermentation.

INTRODUCTION

There is growing interest in the ethanol production from abundant and low-cost waste, for example, agricultural waste [Kim and Dale, 2004; Reijnders, 2008; Sarkar et al., 2012], municipal solid waste and food waste [Ma et al., 2017; Yan et al., 2011] in the modern world. Among these low-cost substrates, municipal solid waste is an abundant raw material with zero cost; due to the excessive concentration of population in cities and the emergence of metropolises, the waste situation is becoming acute. In terms of municipal solid waste disposal methods, waste landfilling is characterized by the maximum practical distribution in the world practice, but judging the by experience of waste management of the leading countries of the world, disposal of wastes using this method at the present time becomes unpromising, since it pollutes the territories and groundwater [Nozhevnikova, 2016].

It should be noted that various factors, including culture, location, weather conditions, as well as the degree of economy and development of a given society, affect the composition of municipal solid waste [Alavi Moghadam et al., 2009]. Solid waste generated in developing countries every year, contains 40–88% food waste [Sharholy et al., 2007; Talyan et al., 2008; Yousuf and Rahman, 2007], indicating that the organic fraction of the waste consists mainly of starch, lignocellulose, and lipids. Starch and lignocellulose have a high potential for conversion to ethanol, while other organic fractions such as lipids cannot be converted to ethanol, but these biodegradable components can be converted to biogas by anaerobic fermentation. Pretreatment can increase the bioavailability of lignocellulose by the cellulase. Among the various methods, hydrothermal pretreatment reduces the formation of fermentation inhibitors, which are formed mainly by sugar degradation. Hydrothermal pretreatment is an

environmentally friendly process because it uses no chemicals; this treatment removes most of the hemicellulose and improves the enzyme availability for cellulose [Taherzadeh and Karimi, 2008].

MATERIALS AND METHODS

Fractional models of organic components, which were collected in accordance with the approximate chemical composition of municipal solid waste, were used in this qualitative research implementation, as well as a sample with organic components from the municipal solid waste landfill of the "Tartyp" Joint Stock Company (JSC), Almaty. A total of 5 fractions with various composition and mass were collected:

- Natural sample from the municipal solid waste landfill of Almaty (1500 g);
- lipids containing model fraction (509 g);
- Cellulose containing model fraction (850 g);
- Carbohydrates containing model fraction (900 g);
- Combined fraction (cellulose – 850 g, carbohydrates – 900 g, lipids – 500 g).

The experimental procedure consists of the following main stages: preliminary hydrothermal treatment, enzymatic hydrolysis (amylase, glucavamarin, amylosubtiline, cellulase), ethanol fermentation (alcohol yeast) of the liquid waste fraction.

The sample was formed, moisture content and pH were determined, and then it was hydrothermally treated at 120°C for 4 hours. Qualitative reactions for the presence of starch and glucose were carried out after hydration, then the samples were separated into liquid and solid fractions and the fermentation began. Afterwards, 1.5 gamylosubtilin was added to the liquid part of the sample for 1.5 hours at 65°C, then 2 g of glucavamarine for 1.5 hours at 50°C. Subsequently, 2 g of cellulase was added to the solid part of the sample for 1.5 hours at 50°C and 1.5 g of amylase at 65°C for 1.5 hours. The fermentation was followed by ethanol fermentation, for this purpose alcoholic yeast (15 g) is added to the liquid part for ethanol production [Mahmoodia et al., 2018].

RESULTS AND DISCUSSION

In the qualitative research, liquids with various volumes were obtained from each model sample after hydrothermal pretreatment, fermentation, and ethanol fermentation.

The obtained samples with liquids were analyzed by Gas chromatography–mass spectrometry (GC-MS) (Agilen 7890A \ 5975C) to determine the chemical composition. Passing through the chromatograph, the samples are separated into components, and the mass spectrometer is responsible for their identification and analysis. This detection mode is highly accurate, its essence is to record readings not over the total volume of the incoming ion current, but over the maximum ions for the supposed molecules, and curves of the time dependent signal are plotted. The chromatogram is a graphical representation of the detector signal used to measure the concentration of substances in the eluate, from the time of the mobile phase. Schematically, chromatograms are the Gaussian peaks sequence on a baseline.

The analysis of the model combined sample detected the presence of the following components in the composition: ethanol, 1-butanol, 3-methyl, propanoic acid, 2-methyl, oxime, methoxy-phenyl, and l-α- terpineol. Table 2 provides the data on retention time, peak areas and components, abundance and concentration of these substances.

In accordance with Table 2, a graph of gas chromatography–mass spectrometry was provided, which shows the result of recording the time dependent abundance at the column outlet. The concentration of each peak in percent is calculated from the peak area.

Table 3 shows the results of gas chromatography analysis of the lipids containing sample, with the following composition of this sample: ethanol, 1-butanol, 3-methyl, propanoic acid, 2-methyl, butanoic acid, butyric acid, 3-methyl, oxime,

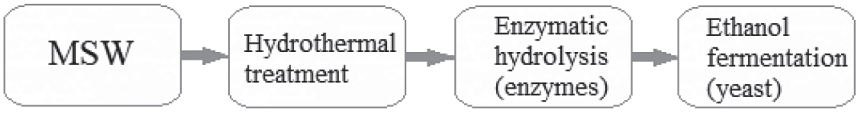

Figure 1. Experiment sequence diagram

Table 1. Ethanol fermentation results

No.	Sample Name and mass (g)	The amount of liquid after ethanol fermentation (ml)
1.	Natural sample from the municipal solid waste landfill of Almaty (1500 g)	135 ml
2.	Lipids containing model fraction (509 g)	80 ml
3.	Cellulose containing model fraction (850 g)	117 ml
4.	Carbohydrates containing model fraction (900 g)	95 ml
5.	Combined fraction (cellulose - 850g, carbohydrates - 900g, lipids - 500g)	162 ml

Table 2. Components of the combined sample

Peak No.	Ret time (min)	Area (S)	Component	Abundance	%
1	1,681	4237936015	Ethanol	94	95.8
2	3,978	151571481	1-Butanol, 3-methyl-	62	3.4
3	6,389	3217162	Propanoic acid, 2-methyl-	73	0.1
4	9,499	28243644	Oxime-, methoxy-phenyl-_	77	0.6
5	17,185	2258941	L-α-Terpineol	71	0.1

methoxy-phenyl, pyrazine, tetramethyl, phenylethyl alcohol, triethyl citrate, phthalic acid, and butyl hex-3-yl ester. The retention time required to elute the substance corresponds to the time of the peak maximum appearance on the chromatogram, the peak areas, the abundance or signal of the detector, as well as the data on the substances percentage in the sample.

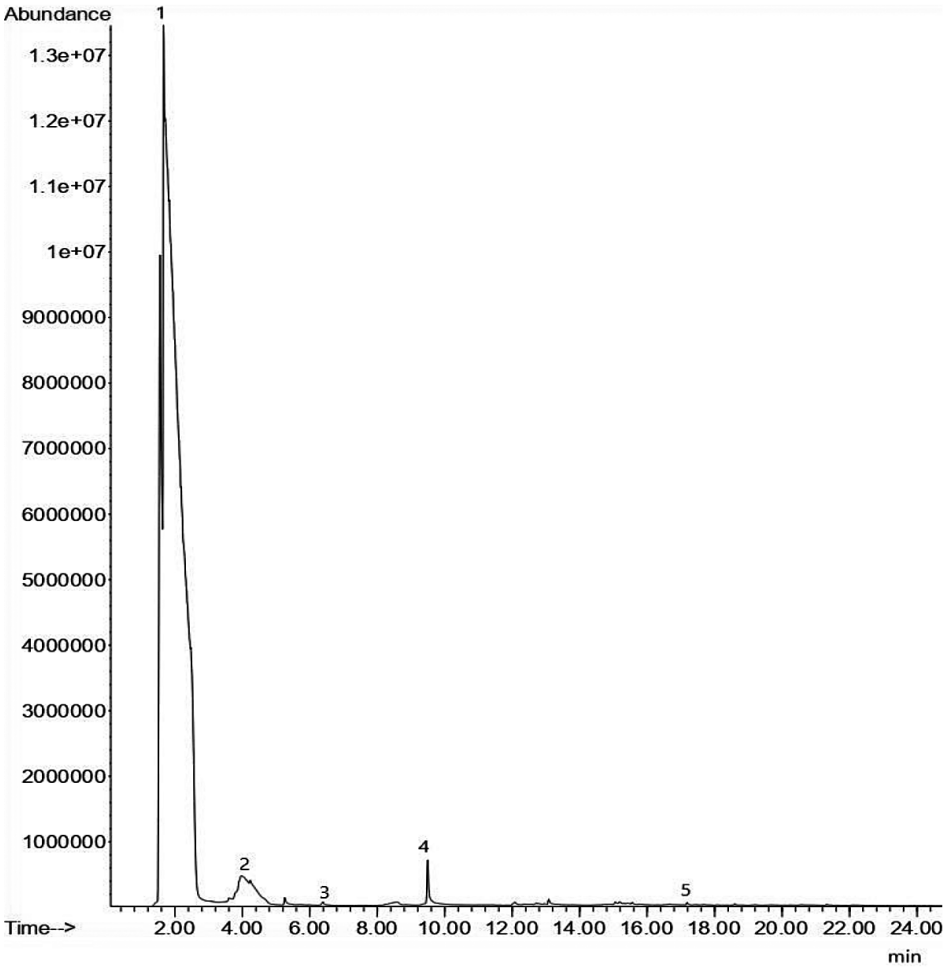

Figure 2. Chromatogram of the time (time) dependent components concentration of the combined sample (abundance)

Table 3. Concentration of the lipids containing sample components

Peak No.	Ret time (min)	Area (S)	Component	Abundance	%
1	1,733	2084267735	Ethanol	93	93.85
2	3,974	66427254	1-Butanol, 3-methyl-	81	2.99
3	6,623	3468608	Propanoic acid, 2-methyl-	83	0.16
4	7,407	4610257	Butanoic acid	77	0.21
5	8,522	10123063	Butanoic acid, 3-methyl-	63	0.46
6	9,576	31078988	Oxime-, methoxy-phenyl-_	85	1.40
7	15,176	9813476	Pyrazine, tetramethyl-	80	0.44
8	16,477	9109129	Phenylethyl Alcohol	74	0.41
9	27,674	1155125	Triethyl citrate	75	0.05
10	33,817	909606	Phthalic acid, butyl hex-3-yl ester	77	0.04

The lipid sample contains characteristic aromatic heterocyclic organic compounds in its component composition, such as Pyrazine, monobasic short-chain saturated fatty acids (Butyric acid), and monohydric phenylethyl alcohol contained in essential oils, which indicates the reliability of the analysis method.

According to the data in Table 3, the provided chromatogram clearly shows the dependences of the components abundance and the retention time (the time required for substance elution corresponds to the time of the maximum peak appearance in the chromatogram). Each peak with the corresponding number reflects the component presented in the table.

The results of the mass spectrometry analysis of the sample with cellulose detected the following components concentrations: ethanol, 1-butanol, 3-methyl oxime, methoxy-phenyl, and dibutyl phthalate. This sample showed the lowest percentage of ethanol, compared to the others, since cellulose contains ligninocellulose in its

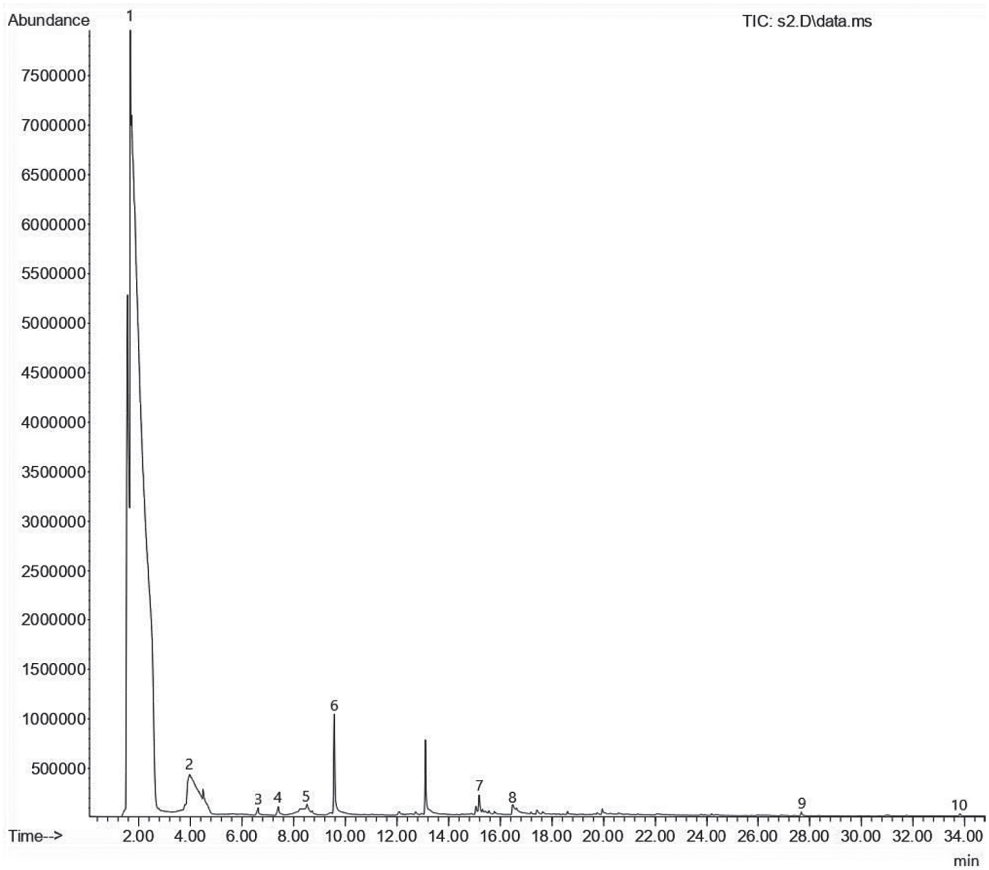

Figure 3. Graph of the lipids containing sample components ratio

Table 4. Concentration of cellulose containing sample components

Peak No.	Ret time (min)	Area (S)	Component	Abundance	%
1	1,718	2571350344	Ethanol	92	90.84
2	3,986	201445006	1-Butanol, 3-methyl-	81	7.12
3	9,513	37545433	Oxime-, methoxy-phenyl-_	79	1.33
4	33,818	20161521	Dibutyl phthalate	96	0.71

composition, which has a dense structure. Lignin is a complex molecule consisting of phenylpropane units linked in a three-dimensional structure, which is especially difficult to biodegrade, the higher the lignin fraction, the higher the chemical and enzymatic degradation resistance.

Figure 4 shows the graph of the time (peak) dependent detector signal (substance abundance) in the cellulose containing sample. Each component corresponds to the time and peak registering the detector response.

In the sample with carbohydrates, after analysis on the gas chromatograph, the content of ethanol (96.27%) was detected; the sample also contains such components as: 1-butanol, 3-methyl, oxime, and methoxy-phenyl.

The chromatogram of the carbohydrates containing model sample is shown in Figure 5, where each component corresponds to the peak number and retention time.

A natural sample from the municipal waste disposal landfill of Almaty, after a qualitative research with fermentation, showed the highest ethanol content of 97.45% compared to other samples, as well as such substances as oxime-, methoxy-phenyl, ethyl 2- (5-methyl-5-vinyltetrahydrofuran-2 –yl), propan-2-yl carbonate, pyrazine, tetramethyl, 2h-pyran-3-ol, 6-ethenyltetrahydro-2,2,6-trimethyl, and α-terpineol. Table 6 shows the peak time, the area and the abundance of each component, and the concentrations of these substances.

The chromatogram of the substances abundance, the peaks area and the retention time of the sample with the organic fraction of the municipal solid waste landfill in Almaty is shown in Figure 6.

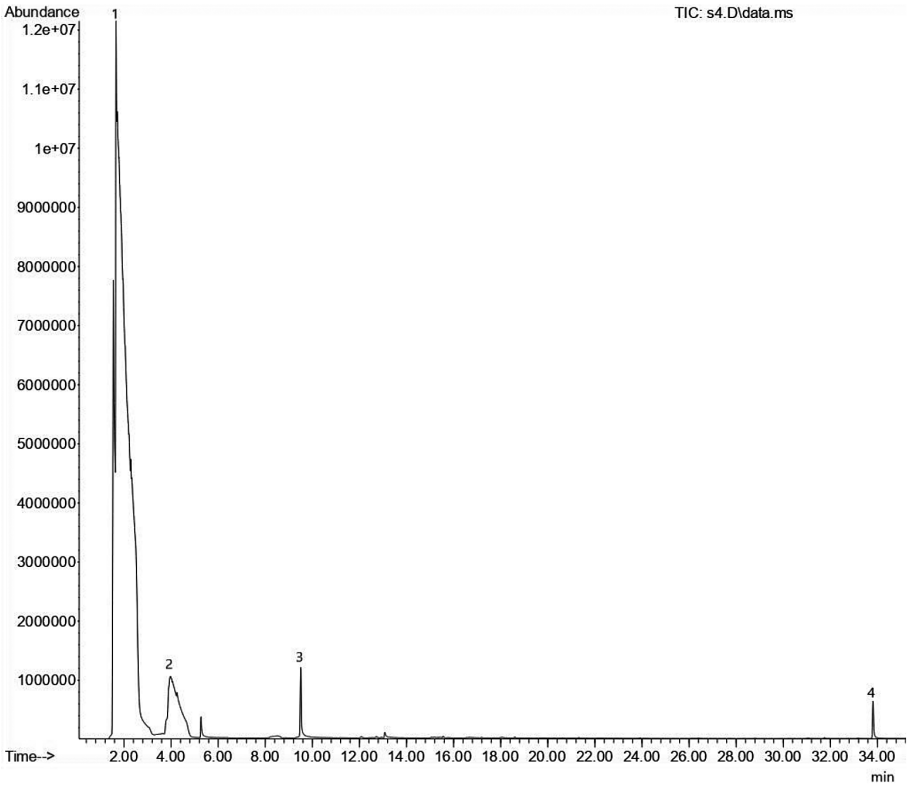

Figure 4. Chromatogram of the dependence of the substances concentration and the time of the cellulose containing sample

Table 5. The carbohydrates containing sample components concentration

Peak #	Ret Time(min)	Area(S)	Component	Abundance	%
1	1,715	3312233598	Ethanol	93	96.28
2	4,215	88291610	1-Butanol, 3-methyl-	69	2.57
3	9,497	39044278	Oxime-, methoxy-phenyl	79	1.15

CONCLUSIONS

Ethanol is present in large amounts in all analyzed samples; butanol is also present in the composition, which indicates that pretreatment, fermentation and ethanol fermentation had a positive effect on the bioethanol production. The ethanol concentration in a natural sample obtained from the landfill has the highest rate of 97.45%, compared to the others, which indicates that the natural sample of municipal solid waste from the landfill in Almaty has the greatest potential for its production. Model samples with different homogeneous and heterogeneous composition and also a natural sample from the landfill were selected to assess the differences in the degree of fermentation and ethanol concentration. On the basis of the results, it can be judged that the combination of components and a heterogeneous composition like in the natural waste sample, may contribute to increase the ethanol concentration and its other isomers. Probably, the mixed raw materials contain more components and the effect of enzymes improves their bioavailability and prepares them for ethanol fermentation, and pretreatment promotes the cleavage of lignin and

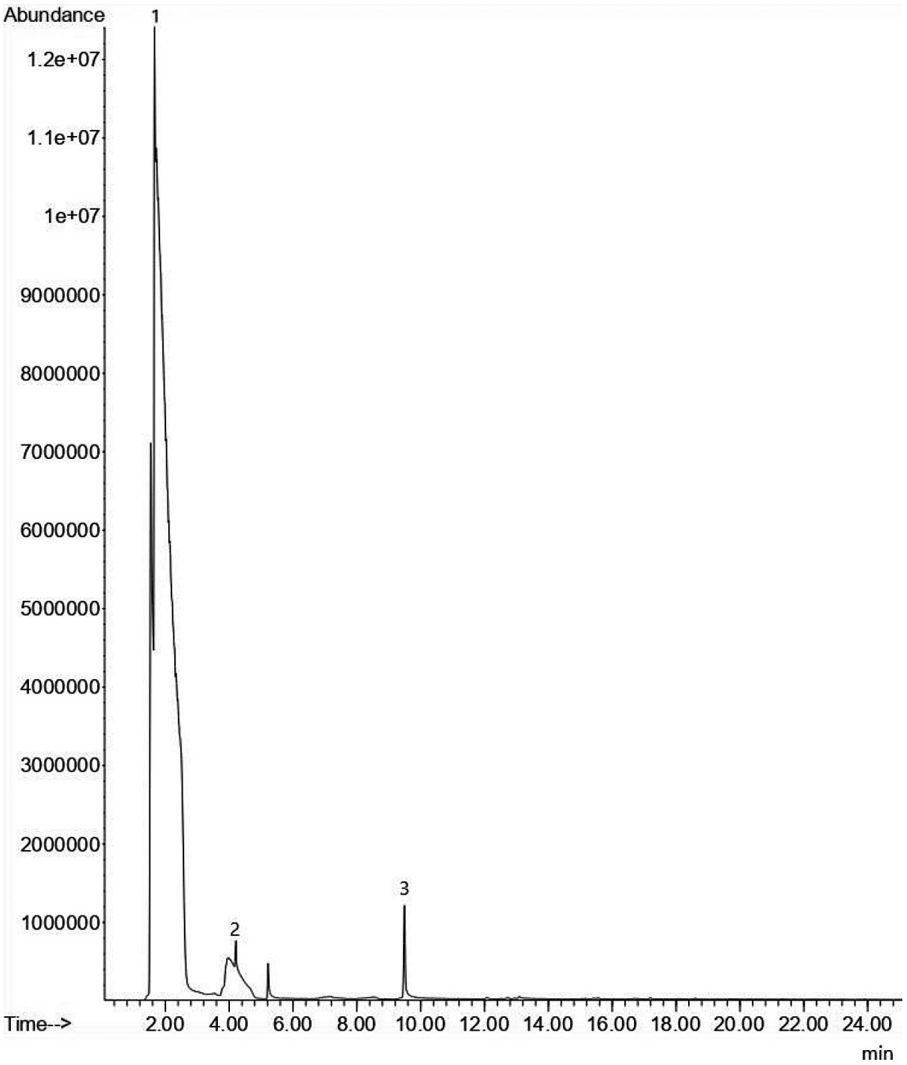

Figure 5. Graph of the time dependent carbohydrate containing sample components concentration

Table 6. The natural sample components concentration obtained from the municipal solid waste landfill of the "Tartyp" Joint Stock Company (JSC) in Almaty:

Peak No.	Ret time (min)	Area(S)	Component	Abundance	%
1	1,731	2339904556	Ethanol	91	97.45
2	9,559	44417720	Oxime-, methoxy-phenyl-_	80	1.85
3	14,317	5705926	Ethyl 2-(5-methyl-5-vinyltetrahydrofuran-2-yl)propan-2-yl carbonate	86	0.24
4	15,18	7123396	Pyrazine, tetramethyl-	81	0.30
5	16,779	2328081	2H-Pyran-3-ol, 6-ethenyltetrahydro-2,2,6-trimethyl-	63	0.10
6	17,185	1557327	α-Terpineol	67	0.06

lignin containing cellulose, which are present in many components of municipal solid waste.

The experiment was carried out under laboratory conditions with small masses of samples, after obtaining ethanol, on an industrial scale, there will be a large amount of residues of the solid part of the waste, which can be exposed by the method of anaerobic fermentation for methane production and its further use as an alternative source of energy, which in its the queue has a good economic benefit, since the waste raw materials have zero cost. Therefore, high concentration Ethanol, as well as – biogas (methane) can be produced jointly from organic components of municipal

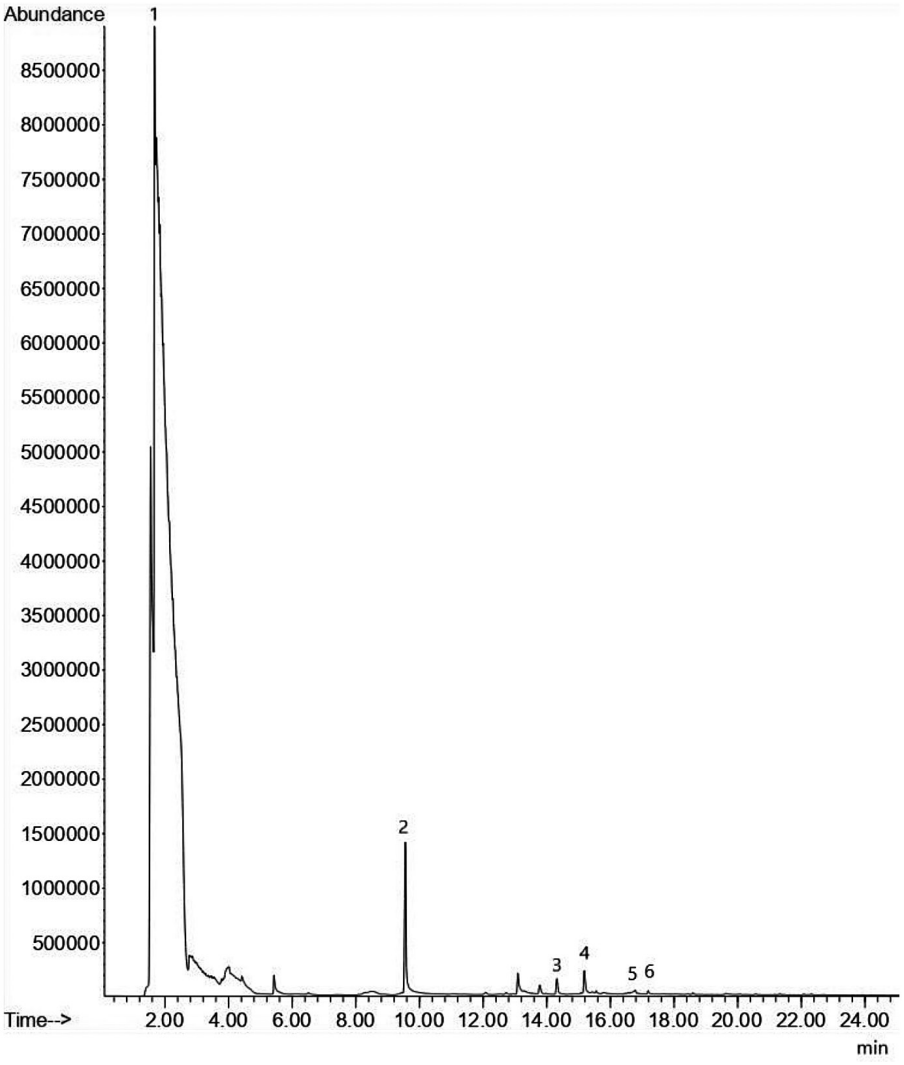

Figure 6. Graph of the natural sample components concentration obtained from the municipal solid waste landfill of the "Tartyp" Joint Stock Company (JSC) in Almaty

solid waste. In addition to the direct economic benefit, the production of biogas and bioethanol from waste can:

- reduce the waste sites volume;
- reduce greenhouse gas emissions;
- reduce the natural gas consumption.

It is necessary to develop alternative energy to support the global efforts to reduce the greenhouse gas emissions and improve the climate by producing ethanol and methane from the organic fraction of municipal solid waste.

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