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Production of syngas from agricultural wastes by plasma-chemical method

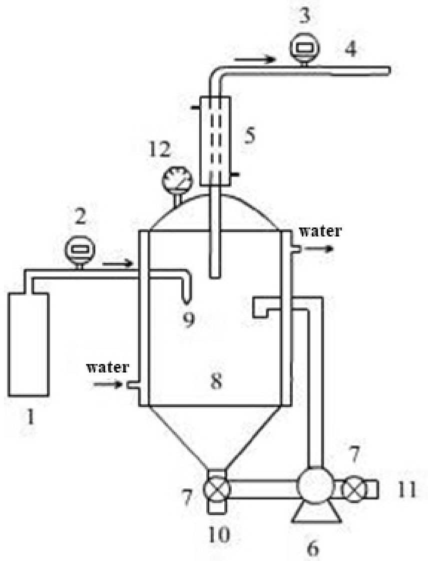
A promising technology for utilization of agricultural waste is chemical plasma technology based on high-temperature plasma-chemical effects and the decomposition of hydrocarbon products to produce synthesis gas. Emulsified mixture of cow dung and water was placed into the reactor for producing synthesis gas. On entering the emulsion is exposed to flame of a gas burner with a combustion temperature of two thousand degrees. The plasma-chemical reactor was regularly tested in different modes to find the best mode for the production of synthesis gas and its composition. The stability of the voltage at the output of the electric generator was monitored at various loads. As a result, a stable operation of the gas generator was achieved. Chemical characteristics of syngas obtained appeared to be high: gas was pure and without dust, CO_2 content was low, but content of hydrogen and CO was high, namely 31.62 % and 37.28, respectively. Gas quality was checked by visual observation of the burner flame and the temperature of the burning gas using an infrared pyrometer. The stability of the flame and the stability of the temperature of combustion characterize the quality of synthesis gas. It is shown experimentally that the plasma-chemical treatment of hydrocarbons and agricultural wastes is a highly effective method for producing synthesis gas.

Keywords: plasma chemistry, synthesis gas, hydrogen, carbon monoxide, agricultural waste, recycling.

The development of power industry is based on the use of renewable energy sources and stimulated by the lack of traditional fuel and energy resources and environmental problems. Currently, there is an increasing interest in creating new environmentally friendly technologies based on plasma processes. One of the most promising substitutes for classic fuels is synthesis gas, which is formed in the processing and recycling of oil and gas, coke-chemical, energy industries and agriculture waste [1, 2]. Due to modern developments, synthesis gas is obtained by gasifying not only coal and oil, but also more unconventional carbon sources, up to household and agricultural waste.

Synthesis gas is mainly a mixture of carbon monoxide and hydrogen. It is produced industrially by steam reforming of methane, partial oxidation of methane, plasma gasification of waste and raw materials, coal gasification [3, 4]. The ratio of components in the synthesis gas varies in a wide range, because it depends both on the raw materials used and on the type of conversion — by water vapor or by oxygen. Depending on the method of producing synthesis gas, the ratio of CO: H_2 in it varies from 1: 1 to 1: 3. Typically, the percentage of substances in raw crude synthesis gas is as follows, %: CO — 15–18; H_2 — 38–40; CH_4 — 9–11; CO_2 — 30–32.

The most promising technology for the disposal of agricultural waste is a plasma-chemical technology. It is based on a high-temperature plasma-chemical effect on the recyclables to produce synthesis gas and the complete decomposition of the recyclable waste [5, 6]. The schematic diagram of the laboratory setup is shown in Figure 1.



1 — cylinder (propane-butane); *2, 3* — gas meters; *4* — gas outlet; *5* — dephlegmator; *6* — circulation pump; *7* — valve; *8* — reactor; *9* — gas burner; *10* — drain; *11* — loading of raw materials; *12* — pressure gauge

Figure 1. Laboratory set-up of plasma-chemical waste processing into synthesis gas

An emulsified mixture of cow manure and water was fed into a 8 L metal cell (reactor) to produce synthesis gas. The incoming emulsion was affected by the flame of a gas burner (domestic propane-butane gas) with a temperature of up to 2000 ºC. During the reaction for 15 minutes, the volume of evolved gas amounted to 0.176 m^3. The volume of consumed domestic gas in the burner was 0.036 m^3.

In this technology, cattle manure was the main material used in the production of synthesis gas. The composition of manure is greatly influenced by the specific gravity of concentrated feed in the diet and by the quantity and quality of litter. Manure contains up to 80 percent of water (source of water vapor) and up to 20 percent of organic matter (source of carbon) [7, 8]. The chemical composition of manure is given in Table 1.

Table 1

The chemical composition of the feedstock

Cattle manure	Chemical composition (%)							
	Water	Organic matter	Nitrogen (common)	(P_2O_5)	(K_2O)	(CaO)	(MgO)	Iron oxide and Aluminum oxide (R_2O_3)
Cattle	77.3	20.3	0.45	0.23	0.50	0.40	0.11	0.05

The resulting mixture of gases was collected in plastic containers every five minutes for investigation (burning temperature, composition, humidity, etc.). The analysis carried out on the Kristall Lux 4000-M gas chromatograph with a thermal conductivity detector showed a stable gas composition for a long time of 2–5 days. The composition and quantitative ratios between the components of the mixture obtained by means of a plasma-chemical set-up correspond to the composition of synthesis gas. The composition and volume fractions of the components of the evolved gas mixture are shown in Table 2.

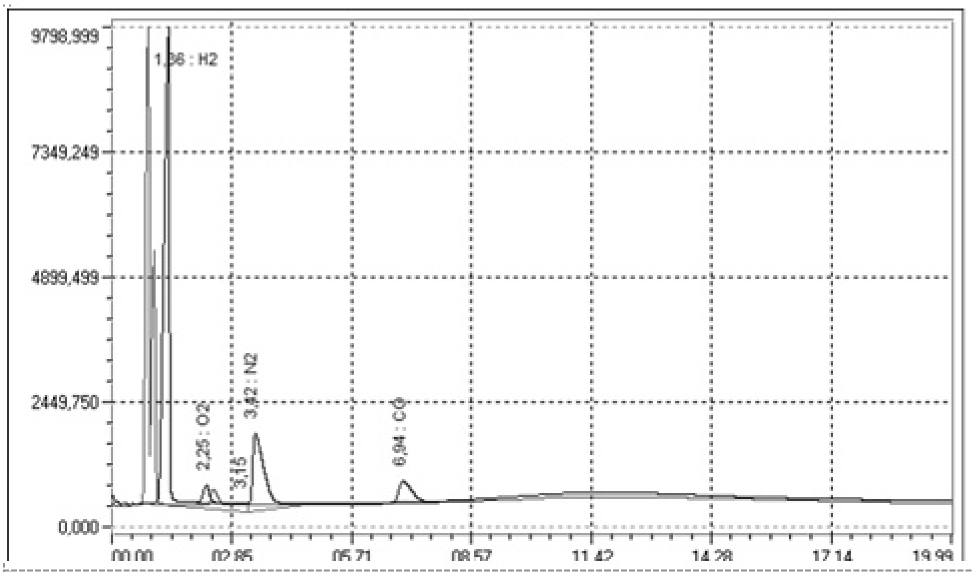
Table 2

The composition of the synthesis gas, depending on the operating time of the reactor

The operating time of the reactor, min	Composition of the output gas, %				
	H_2	O_2	CO_2	N_2	CO
10	14	8.6	3.6	55.0	17
15	25	4.0	4.5	15	23
20	45	0.0	6.5	0.5	43

As it seen from Table 2, an increase in the operating time of the reactor leads to improving qualitative composition of the output gas, because the content of CO_2, O_2, N_2 decreases, and the content of CO and H_2 increases.

Figure 2 shows the program window of the NetChrome chromatograph, where one of the results of the chromatographic analysis of the output gas is shown.



№	Component	Retention time,min	Concentration, %
1	H2	1,36	4,575E+01
2	O2	2,25	0,00
3	CO2	2,42	6,572E+00
4	N2	3,42	5,579E-01
5	CO	6,94	4,300E+01
			1,181E+02

Figure 2. Synthesis Gas Chromatogram

The plasma-chemical reactor was regularly tested in different modes to find the best mode for the production of synthesis gas and its composition. The stability of the voltage at the output of the electric generator was monitored at various loads. Gas quality was checked by visual observation of the burner flame and the temperature of the burning gas using an infrared pyrometer. The stability of the flame and the stability of the temperature of combustion characterize the quality of synthesis gas. The presence of water vapor, mechanical impurities at various burner modes with different ratios of air supplied and synthesis gas was constantly monitored. As a result, a stable operation of the gas generator was achieved. The composition and volume fractions of gas obtained in a steady mode of operation are presented in Table 3.

Table 3

The composition and volume fraction of the gas mixture obtained by the plasma-chemical method from cattle manure

No.	Gas components	Processing time, min	
		3	15
		gas composition, %	
1	H_2	25.04	31.62
2	O_2	0.18	0.74
3	CO	35.69	37.28
4	CO_2	1.23	11.75
5	N_2	5.99	4.91

The gas mixture obtained processing of 15 minutes contained 31.6 hydrogen and 37.28 carbon monoxide (1: 1 ratio). During this time, the ratio of consumed and obtained synthesis gas amounted to 1:30. The amount of both consumed and released gas was measured by gas meters. The released synthesis gas was burned with an tranquil flame and had a good caloric effect (burning temperature in air 2500 K).

The synthesis gas was pumped out by a pump-compressor. The compressor pumps synthesis gas into the tank-gasholder (2000 L) until pressure reaches 8 atmospheres. The pressure in the gas-holders is controlled by gas manometers; the gas tanks are equipped with gas reducers and gas cranes. The quality of the synthesis gas was checked using an electric generator, which operated in the gas fuel mode. After filling the gasholders, the synthesis gas was supplied to the gas generator «Interskol EBG-5500» to generate electrical energy. It worked steadily for 1 hour, with a load capacity of 2 kilowatts.

As a result, a method for producing synthesis gas from agricultural waste was proposed with the help of processing cattle manure by a plasma chemical method. It has been experimentally shown that plasma-chemical processing of hydrocarbon and agricultural wastes is a highly efficient method for producing synthesis gas, which will be used as a fuel for heating and producing electricity at a gas power station. The developed plasma-chemical set allows processing not only agricultural waste, but also any waste containing organic components.

Advantages of the technology are follows:

– there are no polluting emissions compared with direct combustion methods;

– high velocity gasification and the availability of liquefied gas and electricity at power stations;

– utilization of hydrocarbon waste and production of fertilizer from agricultural waste.

References

1 Петров С.В. Управление процессом плазменной переработки твердых органических отходов / С.В. Петров, С.Г. Бондаренко, Е.Г. Дидык, А.А. Дидык // Вiсник НТУУ «КПI» Хiмiчна iнженерiя, екологiя та ресурсосбереження. Науковий сбiрник. — 2009. — Т. 3, № 3. — С. 29–38.

2 Beychok M.R. Process and environmental technology for producing SNG and liquid fuels, U.S. EPA, report EPA-660/2–75–011, May 1975. — P. 12.

3 Жуков М.Ф. Новые технологии сжигания топлива / М.Ф. Жуков, Б.И. Михайлов и др. // Энергетика страны и регионов. Теория и методы управления. — Новосибирск: Наука. Сиб. отд., 1988. — С. 176−190.

4 Мустафин Е.С., Касенов Р.З., Пудов И.М., Айнабаев А.А., Дюсекеева А.Т., Кездикбаева А.Т. Переработка углеводородных и сельскохозяйственных отходов в синтез-газ методом плазмохимии / ЭКСПО-2017: Технологии будущего: материалы Республиканской научно-практической конференции (21–22 октября 2016 года). — Караганда, 2016. — С. 92–95.

5 Тухватуллин А.М., Засыпкин И.М. Плазмохимическая технология переработки углеводородного сырья, обезвреживания и утилизации токсичных отходов // Генерация низкотемпературной плазмы и плазменные технологии. Проблемы и перспективы. (Низкотемпературная плазма. Т. 20). — Новосибирск: Наука. Сиб. отд. РАН, 2004. — С. 307−327.

6 Патон Б.Е., Чернец А.В., Маринский Г.С., Коржик В.Н., Петров С.В. Перспективы применения плазменных технологий для уничтожения и переработки медицинских и других опасных отходов. Ч. 1 // Современная электрометаллургия. — 2005. — № 3. — С. 54–63.

7 Пархоменко В.Д., Сорока П.И., Моссэ А.Л. и др. Плазмохимическая технология. Низкотемпературная плазма. — Новосибирск: Наука. Сиб. отд., 1991. — Т. 4. — С. 8–10.

8 Мамченков И.П. Навоз // Большая советская энциклопедия: в 30 т. — Т. 17 / И.П. Мамченков; гл. ред. А.М. Прохоров. — М.: Сов. энцикл., 1974. — С. 1969–1978.

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Плазмахимиялық әдіспен ауылшаруашылық қалдықтарынан синтез-газ алу

Ауылшаруашылық қалдықтарын толықтай ыдырату арқылы синтез-газ ала отырып, жоюдың перспективті әдісі жоғарытемпературалы плазмохимиялық әсерге негізделген технология болып табылады. Синтез-газды алу үшін реакторға сиырдың көңі мен су қоспасының эмульсиясы салынды. Эмульсияға екі мың градус температурамен әсер етілді. Алынған синтез-газдың химиялық сипаты жоғары болды: газ таза, шаңсыз, құрамында CO_2 аз, ал сутегі мен CO мөлшері жоғары сәйкесінше 31,62 % және 37,28 %. Синтез-газды өндіруді және оның құрамын жақсарту үшін плазмахимиялық реакторға әртүрлі режимдерде сынақ жүргізілді. Электргенераторындағы кернеудің тұрақтылығы түрлі жүктемелерде бақыланды. Нәтижесінде газ генераторының тұрақты жұмысына қолжеткізілді. Зерттеу жұмысының нәтижесі бойынша көмірсутек пен ауылшаруашылық қалдықтарын плазмахимиялық өңдеу синтез-газ алудың жоғары әрі тиімді әдісі болып табылады.

Кілт сөздер: плазмохимия, синтез-газ, сутегі, көміртегі тотығы, ауылшаруашылық қалдықтары, қайта өңдеу.

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Получение синтез-газа из сельскохозяйственных отходов плазмохимическим методом

Перспективной технологией утилизации сельскохозяйственных отходов является плазмохимическая технология, основанная на высокотемпературном плазмохимическом воздействии и полном разложении углеводородных продуктов с получением синтез-газа. Для получения синтез-газа в реактор подавали эмульгированную смесь коровьего навоза и воды. На поступающую эмульсию воздействовали пламенем газовой горелки с температурой горения до двух тысяч градусов. Регулярно проводили испытания плазмохимического реактора в разных режимах для поиска лучшего режима производства синтез-газа и его состава. Проводился контроль стабильности напряжения тока на выходе электрогенератора при различных нагрузках. В результате был достигнут устойчивый режим работы газогенератора. Химические характеристики полученного синтез-газа оказались высокими: газ чистый и без пыли, содержание CO_2 — низкое, а водорода и CO — высокое, а именно 31, 62 % и 37,28 % соответственно. Качество газа проверялось при визуальном наблюдении за пламенем горелки и температурой горящего газа с помощью инфракрасного пирометра. Устойчивость пламени и стабильность температуры горения характеризуют качество синтез-газа. Таким образом, экспериментально показано, что плазмохимическая обработка углеводородных и сельскохозяйственных отходов является высокоэффективным методом получения синтез-газа.

Ключевые слова: плазмохимия, синтез-газ, водород, монооксид углерода, сельскохозяйственные отходы, переработка.

References

1 Petrov, S.V., Bondarenko, S.G., Didyk, E.G., & Didyk, A.A (2009). Upravlenie protsessom plazmennoi pererabotki tverdykh orhanicheskikh otkhodov [Managing the process of plasma processing of solid organic waste]. *Visnik NTUU «KPI» Khimichna inzheneriia, ekolohiia ta resursosberezhennia. Naukovii sbirnik. — Herald STU «KPI» Chemical Engineering and Resource Saving Ecology. Scientific collection, 3, 3,* 29–38 [in Russian].

2 *Beychok, M.R.* Process and environmental technology for producing SNG and liquid fuels, U.S. EPA, report EPA-660/2–75–011, May 1975. — P. 12.

3 Zhukov, M.F., & Mikhailov, B.I. et al. (1988). Novye tekhnolohii szhihaniia topliva [New technologies of fuel combustion]. *Energetika strany i regionov. Teoriia i metody upravleniia. — Energy of the country and regions. Theory and methods of management.* Novosibirsk: Nauka, Sibirskoe otdelenie RAN, 176–190 [in Russian].

4 Mustafin, E.S., Kassenov, R.Z., Pudov, I.M., Ainabaev, A.A., Dyusekeeva, A.T., & Kezdikbaeva, A.T. (2016). Pererabotka uhlevodorodnykh i selskokhoziaistvennykh otkhodov v sintez-haz metodom plazmokhimii [Processing of hydrocarbon and agricultural wastes into synthesis gas using the plasma-chemical method]. Proceedings from: «EXPO-2017: Technologies of the future»: *Respublikanskaia nauchno-prakticheskaia konferentsiia (21–22 oktiabria 2016 hoda) — the Republican scientific and practical conference.* (pp. 92–95). Karaganda [in Russian].

5 Tukhvatullin, A.M., & Zasypkin, I.M. (2004). Plazmokhimicheskaia tekhnolohiia pererabotki uhlevodorodnoho syria, obezvrezhivaniia i utilizatsii toksichnykh otkhodov [Plasma-chemical technology of hydrocarbon raw materials processing, neutralization and utilization of toxic waste]. *Heneratsiia nizkotemperaturnoi plazmy i plazmennye tekhnolohii. Problemy i perspektivy (Nizkotemperaturnaia plazma. T. 20). — Generation of low-temperature plasma and plasma technologies. Problems and prospects. (Low-temperature plasma. Vol. 20).* Novosibirsk: Nauka, Sibirskoe otdelenie RAN, 307–327 [in Russian].

6 Paton, B.E., Chernets, A.V., Marinsky, G.S., Korzhik, V.N., & Petrov, S.V. (2005). Perspektivy primeneniia plazmennykh tekhnolohii dlia unichtozheniia i pererabotki meditsinskikh i druhikh opasnykh otkhodov. Chast 1 [Prospects for the use of plasma technology for the destruction and processing of medical and other hazardous waste. Part 1]. *Sovremennaia elektrometallurhiia. — Modern electrometallurgy, 3,* 54–63 [in Russian].

7 Parkhomenko, V.D., Soroka, P.I., & Mosse, A.L. et al. (1991). *Plazmohimicheskaia tehnolohiia. Nizkotemperaturnaia plazma [Plasma-chemical technology. Low-temperature plasma]*. (Vol. 4). Novosibirsk: Nauka, Sibirskoe otdelenie RAN [in Russian].

8 Mamchenkov, I.P. (1974). Navoz [Manure]. *Bolshaia sovetskaia entsiklopediia — Big Soviet Enciclopedia*. A.M. Prokhorov (Ed.). (Vols. 1–30; Vol. 17). Moscow: Sovetskaia Entsiklopediia [in Russian].