UDC 66.084.2: 661.7
DOI: 10.15587/1729-4061.2018.136371

STUDYING THE INFLUENCE OF THE INTENSITY OF MECHANO-CHEMICAL ACTIVATION ON THE PROCESS OF STEAM CONVERSION OF COAL

A. Luhovskoi
Postgraduate student*
E-mail: artur.lugovskoi@i.ua
M. Glikin
Doctor of Technical Sciences, Professor*
E-mail: maratglik@rambler.ru
S. Kudryavtsev
PhD, Associate Professor*
E-mail: sergeykudryavtsevsnu@gmail.com
I. Glikina
Doctor of Technical Sciences, Professor*
E-mail: irene555@i.ua
*Department of chemical engineering and ecology
Volodymyr Dahl East Ukrainian National University
Centralnyi ave., 59-a, Severodonetsk, Ukraine, 93400

Продовжується вивчення процесу конверсії вугілля в синтез-газ в умовах аерозольного нанокаталізу та обґрунтовано очікувані переваги майбутньої промислової технології. До переваг можна віднести можливість змінювати швидкість реакції шляхом впливу на інтенсивність механохімічної активації каталізатору. Дослідження процесу проводилось в реакторі, де механохімічна активація здійснюється шляхом обертання каталітичної системи. Вплив інтенсивності активації на хімічні реакції в умовах аерозольного нанокаталізу раніше вже був доведений для реакторів із псевдозрідженим та віброзрідженим шаром каталітичної системи. Попередні дослідження виявили, що механохімічна активація впливає на склад продуктів конверсії, а саме на співвідношення $CO:H_2$. Це дозволить в майбутньому швидко переорієнтовувати виробництва синтез-газу під кон'юнктуру ринку органічних продуктів. Результати дослідження показали, що при температурі 750 °C, 1 атм, інтенсивності МХА 2–4 об/с і надлишку вугілля ($C:H_2O=5,5:1$) отримане співвідношення $CO:H_2=1:1,99–1:2,10$ можливо використовувати в отриманні спиртів. При температурі 750 °C, 1 атм, інтенсивності МХА 0–1 об/с і надлишку вугілля ($C:H_2O=5,5:1$) отримане співвідношення $CO:H_2=1:1,19–1:1,35$ можливо використовувати в отриманні складних ефірів. Також відзначена можливість отримання синтез-газу співвідношенням 1:2,3(2,5), який можна застосувати для отримання вуглеводнів. Отримання цього співвідношення в режимі: температура 750 °C, тиск 1 атм, співвідношення вугілля: вода = 1:0,87, інтенсивність МХА 3–4 об/с. А зазначений процес отримання вуглеводнів досліджений при 230 °C, 1 атм, у віброзрідженому шарі аерозолю каталізатора, співвідношення $CO:H_2=1:3$ при 3 Гц і $CO:H_2=1:2$ при 3 і 5 Гц. Результати даної статті є продовженням глобального дослідження процесу переробки вугілля з отриманням необхідного промислового продукту. У цій особливості полягає перевага проведення даного процесу за технологією аерозольного нанокаталізу

Ключові слова: аерозольний нанокаталіз, механохімічна активація, каталітична система, склад синтез-газу, парова конверсія

1. Introduction

The most common industrial technologies for obtaining the synthesis-gas include steam conversion of methane, partial methane oxidation, plasma gasification of waste and raw materials, coal gasification. The raw material for the production of synthesis-gas can be any carbon-containing compound. Typically used are methane or natural gas, liquid fraction of oil, and coal. This process utilizes air, oxygen, water vapor, carbon dioxide and hydrogen as the gasification agents, as well as the mixtures of these compounds. An important parameter for the process of obtaining the synthesis-gas is the ratio $CO:H_2$. The most common industrially applied ratio of $CO:H_2$ ranges from 1:1 to 1:3 [1]. It depends on the need for obtaining a specific reaction product.

The most common technique for obtaining the synthesis-gas is steam conversion of methane. The process occurs in a reforming furnace on the catalyst Ni/Al_2O_3; sometimes the catalyst Fe_3O_4/Cr_2O_3 is used. An important factor is the highly-developed surface of the carrier. Despite the general acceptance and wide application of a given process, it has certain drawbacks. These include:

– a temperature drop for height and cross-section of the catalyst layer in a reforming furnace;

– the difference in resistance of the catalyst layer in different furnace tubes;

– destruction of a catalyst because of insufficient strength of the carriers [1].

One of the issues for the industrial development of this country could be using coal as a starting raw material for the chemical and energy processes. Coal is one of the most common fossil resources of the country. Therefore, the creation of a plant for processing coal into the product required by chemical industry is one of the promising solutions. The study into a process of steam conversion of coal into aerosols of the nanocatalyst in the rotating reactor has been extended.

The principles and advantages of the aerosol nanocatalysis technology (AnC – Aerosol nanoCatalysis) are described in [2]. Using the aerosol of a catalytically-active substance allows the intensification of chemical reactions. Mechanical action contributes to the active state of the catalyst and increases the reaction rate. The state of a catalyst aerosol and constant mechanical action helps reduce catalyst deactivation.

It is known that mechanical action disrupts the structure of the catalyst particle during its collision with any solid surface. Devices for shredding are most often used for obtaining substances in the finely-dispersed state [3]. The defects of structure thus created, as well as the active state of the particle surface, impact the enhancement of reactivity.

In the aerosol nanocatalysis reactor at continuous exposure of the catalyst to mechanochemical activation, there occurs the chemical conversion of substances. It is known that impact mechanical actions and friction leads to:

– changes in the thermodynamic potentials of a substance;

– the formation of defects in the structure of the surface;

– a change in the properties of the surface of the shredded material [4].

The relevance of this work is in the fact that we propose a new technique for obtaining the synthesis-gas, which would make it possible to solve the problems that occur in the most common industrial technologies. Particularly, in the technology of steam conversion of methane. Efficient application of the process of steam coal conversion based on the aerosol nanocatalysis technology could open up new prospects for the development of chemical and petrochemical industry in Ukraine. The raw material, which we propose to use in a given process, is an affordable resource with stocks in this country. The advantage of the proposed technique for obtaining the synthesis-gas is decreasing the resistance and drop in temperature in the catalyst layer. That in turn reduces the gradient of concentrations and temperatures in the reactor, which makes it possible to maintain a uniform rate of reaction and reduce the concentration of a catalyst in the reactor by about 10^6 times.

This paper is continuation of the research into steam conversion of coal in a rotating layer of the nanocatalyst aerosol. The possibility of the process proceeding under conditions of the nanocatalyst aerosol, as well as research results, are presented in paper [1]. We shall consider the effect of the intensity of mechanochemical activation with determining an optimal mode for the stone coal conversion.

2. Literature review and problem statement

Paper [5] reports results of research into products of thermolysis of stone coal: a solid residue of the thermal decomposition of coal, a resinous faction. The authors consider influence of temperature on the composition of decomposition products. They, however, did not highlight a possibility to change the composition by shredding the fraction of stone coal and by mechanical agitation in the process of thermal decomposition.

Work [6] investigated the composition and chemical-technological properties of fractions of stone coal with a different density. It was established that the maximum content of aromatic components of coal is found in the fractions of coal with a density larger than 1.40 g/cm^3. The work, however, failed to highlight the disadvantages of using this fraction of coal to obtain the sought-after intermediates, such as the synthesis-gas.

Paper [7] reports results of studying the process of cracking the mechanically-treated brown coal. The authors drew a conclusion regarding the impact of coal mechanical treatment on the composition of the obtained products. They, however, did not consider the influence of the intensity of mechanical treatment; there is no comparison of various techniques for mechanical treatment.

Study [8] presents results of experimental research into coal gasification in the environment of high-temperature water vapor. The component composition of the resulting gas phase is given. The authors, however, did not consider the influence of the ratio of water vapor and carbon, which is an important control parameter in a given process.

In paper [9], coal was exposed to pyrolysis at temperatures of 650 °C and 850 °C (aging duration is 2 hours). The authors determined parameters of ash content and the yield of volatile substances from the light, medium, and heavy fractions of coal. The work, however, did not address the influence of temperature on the yield of volatile substances. It is not clear why the authors accepted such a temperature interval. No conclusion was drawn about whether one could increase the output of volatile substances, in particular, by exposing the studied samples of coal to agitation.

Work [10] estimated the possibility of burning stone coal at burning furnaces. The results of industrial tests are reported that involved the estimation of temperature change depending on the height of the combustion chamber of the boiler. The data from experiments showed uneven temperature distribution over the height of the combustion chamber of the boiler. The work, however, did not cover the issue on reducing a temperature drop. The authors did not consider the application of agitating mechanisms in order to solve a given problem.

Paper [11] assessed the possibility of burning stone coal at different concentrations of excess air. The experiments were conducted that demonstrated the impact of excess air on the distribution of temperature and combustion products in the burner. The study did not take into account the possibility of using water vapor as a supplement to the air-gas mixture and a change, as a result of this, in the combustion products in the burner.

Study [12] outlined a possibility to burn coal shale in furnaces with a bubble fluidized layer and showed the advantages provided by this technique. It is not clear, however, how the degree of conversion of a combustible material changes during combustion process if one carries out the process not in furnaces with the fluidized layer, but in furnaces with a rotating layer. And how, as a consequence, the concentrations of SO_2 and NO_X would change in the flue gas.

Paper [13] investigated the way in which a replacement of burning impurities for different types of coal had increased the efficiency of coal combustion (the rate of burnout increased); the concentration of NO_X and SO_2 decreased as well. The authors did not consider how mechanical agitation of coal affected the efficiency of its combustion.

Work [14] studied the influence of conditions of the process on the behavior of free radicals in the solid phase of coal during pyrolysis. It was found that temperature is the most important factor that determines the formation and performance of free radicals in the solid phase. However, the factors considered did not include the influence of mechanical agitation of coal.

Paper [15] reported experimental study into a thermal behavior of blends of coal waste. The authors examined the speed of degradation, conversion rate and kinetic parameters. However, they did not consider the influence of adding water vapor to the coal waste. No conclusion was drawn on whether one could improve the efficiency of the process by exposing the examined mixture to agitation.

Study [16] investigated the technique for melting a mixture of coal and ash in a gasifier with the entrained flow. Research results include conversion of coal, the composition of the gaseous product and temperature profile. It was established that the composition of products changed along the length of a reactor (a large part of the reaction proceeded rapidly at the gasifier front). The work did not consider the way the conversion of coal and the composition of products would change when mechanical agitation is employed.

Based on the results of an analysis of scientific literature that addresses the subject under consideration, still unresolved is the problem related to the difficulty to control the composition of gases during conversion and to the ratio $CO:H_2$ while using a specific type of raw material. It is worth noting that the examined and discussed publications from periodical scientific publications failed to investigate the way in which mechanical agitation of coal affected a change in the composition of the conversion products.

Studying the process of steam conversion of stone coal based on the technology of aerosol nanocatalysis in the rotating reactor would make it possible to solve the issues that are identified when analyzing the scientific literature that tackles the examined problem. Namely, the proposed technique for obtaining the synthesis-gas, in order to adjust the ratio $CO:H_2$, includes a control parameter – the intensity of the mechanochemical activation. Owing to it, changing the intensity of mechanochemical activation can help obtain the ratio for the products of conversion depending on the needs of a particular production.

Employing a technique for the conversion of stone coal under conditions of the aerosol nanocatalysis technology will make it possible to reduce the resistance and a temperature drop in the catalyst layer. Applying the aerosol of the catalyst only in a reactor enables the reduction of its concentration by approximately 10^6 times, and the elimination of its mechanical and thermal constraints associated with its use.

The absence of a gradient of the concentrations and temperatures in the reactor for aerosol nanocatalysis makes it possible to maintain a uniform reaction rate. That leads to a uniform process of gasification of coal particles and to the fullest extent of converting the coal raw materials into products of conversion.

3. The aim and objectives of the study

The aim of this study is to determine the influence of the intensity of mechanochemical activation on the course of the process of steam conversion of stone coal under conditions of the aerosol nanocatalysis technology in the rotating reactor. This would make it possible to expand the knowledge when developing the fundamentals of the technology for the conversion of coal into synthesis-gas in order to improve technical and economic indicators.

To accomplish the aim, the following tasks have been set:

– to modernize and improve the node that enables the rotation of a laboratory reactor;

– to conduct research into dependence of the yield of the targeted and side products of conversion on the speed of rotation and to analyze the results obtained;

– to explore a change in the ratio of $CO:H_2$ on the intensity of mechanochemical activation.

4. Preparing the study of the process for obtaining synthesis gas through a steam conversion of stone coal

A detailed schematic of the laboratory installation with a rotating reactor, used to study the process of steam conversion of coal, is given in paper [1]. To study the influence of intensity of mechanochemical activation, we introduced small improvements to the node that enables the rotation of the reactor. Specifically, replacement of the engine that can rotate a reactor at a rate above 5 Hz; replacement of the laboratory transformer that regulates voltage for the engine operation.

General outlay of the rotating reactor is given in Fig. 1.

a *b*

Fig. 1. Reactor for aerosol nanocatalysis: *a* – general view; *b* – inside view

Volume of the laboratory reactor was 90 cm^3. The inner walls of the reactor hold 3 blades.

We begin the experiment by loading a catalytic system and the examined mass of stone coal into reactor. Preparation of the catalytic system is described in paper [1].

In this study, we investigated stone coal (Lisichansk, Ukraine) of the following composition, % by weight: C – 86; H – 4.5; N – 1.5; O – 3.1; S – 3.2; impurities – 1.7. The starting coal mass was shredded to a fraction of 1.2–0.3125 mm. The examined mass of coal was 19 g and 1 g. Density of the coal dust fraction was 633 kg/m^3 [17].

Based on the preliminary research results, we determined the best temperature of conversion. It is 750 °C [1].

The study was conducted without rotation of the reactor and at a rotation speed from 1 to 7 Hz. Rotation of the reactor contributes to the creation and activation of the catalyst aerosol nanoparticles.

For a steam coal conversion air is the undesired component. That is why before conducting the experiment we blew the reactor with nitrogen to displace the air [18].

When the temperature reached 750 °C, we fed water at a rate of 3.43 ml/min and 1.15 ml/min in accordance with the design of experiment (0.2058 and 0.069 l/h, respectively).

The chilled condensate was collected into a tank. The gas sample was separated for further analysis. However, it is a known fact that water vapor is difficult to separate from the gases of conversion. That is why water vapor was partially present in the analyzed samples [19].

Analytical control was performed using the chromatograph «LHM-8». The procedure for a gas chromatography analysis is described in detail in paper [1].

Volume of the gas sample is 20 ml; it is taken to the airtight container. To study the process of steam conversion of coal, we need to know the concentrations of H_2, CO, CO_2, H_2S, CH_4, C_2H_2, C_2H_4, C_2H_6. A chromatograph makes it possible to determine the concentration with an accuracy not less than 0.01 % by volume [19].

5. Experimental research into the process of obtaining the synthesis gas by steam conversion of stone coal

It was established in the course of our experiment that along with the targeted product (CO+H_2), certain hydrocarbons and other substances form. This indicates that there are some other parameters to control the process, which lead to the parallel progress of side reactions [18].

Results of studying the influence of reactor rotation speed are given in Tables 1, 2.

Table 1

Composition of conversion gases (ratio C:H_2O = 5.5:1, water feed rate is 3.43 ml/min, temperature is 750 °C, pressure is 1 bar)

Rotation speed, Hz	Composition of conversion gases, % by volume							CO:H_2	Selectivity	
	H_2	CO	CO_2	CH_4	C_2H_4	C_2H_6	H_2S		(CO)	(CO_2)
0	3.11	2.62	9.27	3.57	0.76	2.62	6.23	1:1.19	8.30	29.37
1	4.56	3.37	12.43	3.95	1.24	3.44	7.47	1:1.35	8.19	30.21
2	10.67	5.35	14.52	4.88	1.84	4.75	8.63	1:1.99	9.35	25.37
3	11.73	5.74	15.58	5.22	1.97	4.98	9.79	1:2.04	9.26	25.15
4	10.32	4.91	14.11	4.72	1.71	4.27	8.30	1:2.10	9.04	25.98
5	8.27	4.22	13.78	4.47	1.44	3.95	7.97	1:1.96	8.53	27.84
6	6.32	3.53	13.17	4.22	1.27	3.71	7.72	1:1.79	7.86	29.32
7	5.89	3.36	12.75	4.03	1.19	3.56	7.60	1:1.75	7.81	29.55

Table 2

Composition of conversion gases (ratio C:H_2O = 1:0.87, water feed rate is 1.15 ml/min, temperature is 750 °C, pressure is 1 bar)

Rotation speed, Hz	Composition of conversion gases, % by volume							CO:H_2	Selectivity	
	H_2	CO	CO_2	CH_4	C_2H_4	C_2H_6	H_2S		(CO)	(CO_2)
0	2.91	2.24	9.09	3.34	0.72	2.54	6.12	1:1.30	7.41	30.08
1	4.22	3.01	11.61	3.82	1.02	3.19	7.28	1:1.40	7.85	30.27
2	8.94	3.72	13.45	4.51	1.78	4.35	8.37	1:2.40	7.26	26.24
3	10.67	4.28	15.07	5.10	1.95	4.94	9.71	1:2.49	7.30	25.71
4	8.60	3.65	13.02	4.49	1.58	3.98	7.86	1:2.36	7.49	26.71
5	7.03	3.34	12.71	4.31	1.34	3.66	7.75	1:2.10	7.40	28.16
6	6.10	3.08	12.42	4.06	1.23	3.47	7.51	1:1.98	7.24	29.18
7	5.38	2.87	12.07	3.91	1.08	3.39	7.44	1:1.87	7.07	29.72

Next, we consider dependences of the composition of conversion gases and the resulting ratio of CO:H_2 on the reactor rotation speed. Results will be presented for different loads of coal and for different water feed rate.

Fig. 2 shows the influence of rotation speed on the direct yield of synthesis-gas at a different ratio of C:H_2O.

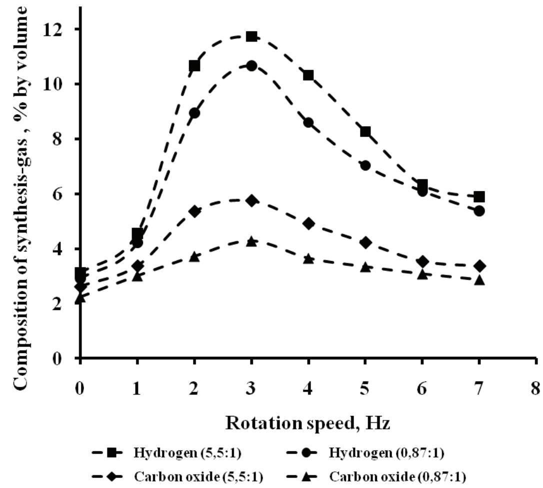

Fig. 2. Dependence of the synthesis-gas yield on rotation speed at different ratios of (C:H_2O=0.87:1) and (C:H_2O=5.5:1). The curves given here illustrate a possible type of dependence

It is noted that the speed of rotation exerts a particular influence on yield of the synthesis-gas. In this case, a rotation speed of 3 Hz produces the maximum amount of the targeted product both at the excess of coal and at its deficit.

Fig. 3 shows the influence of reactor rotation speed on the output of side products (carbon dioxide and hydrogen sulfide).

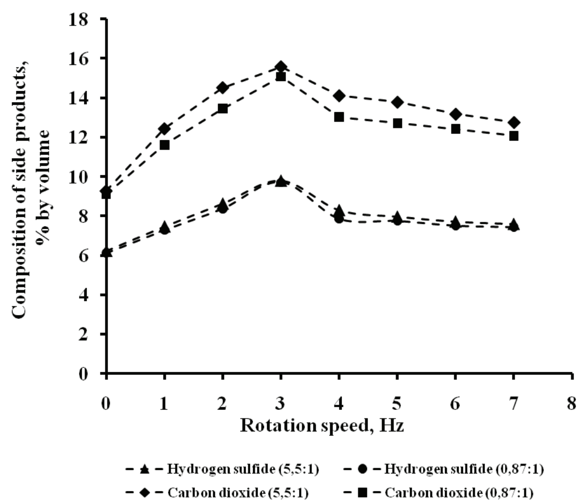

Fig. 3. Dependence of output of by-products on the speed of rotation at different ratios of (C:H_2O=0.87:1) and (C:H_2O=5.5:1). The curves given here illustrate a possible type of dependence

As shown in Fig. 3, a rotation speed of 3 Hz also contributes to the maximum yield of by-products. In this case, the formation of by-products occurs almost regardless of the ratio of the starting reagents.

Fig. 4 shows the dependence of change in the ratio of $CO:H_2$ on the speed of rotation at different load of coal and at a different water feed rate.

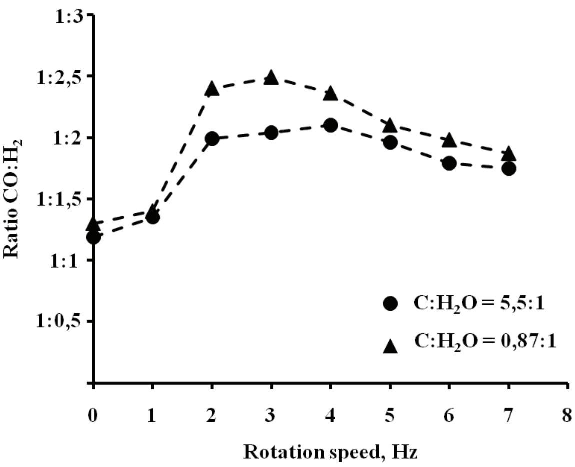

Fig. 4. Dependence of change in the ratio of $CO:H_2$ on the speed of rotation. The curves given here illustrate a possible type of dependence

One can note a change in the output of synthesis-gas while increasing the speed of rotation both towards a growth and decline. Speed of rotation of the reactor is one of the factors that affect the composition of the synthesis-gas, allowing it to vary. Note that at a speed of rotation of 1 Hz we obtain ratio $CO:H_2 \approx 1:1$, which is mostly common for the production of esters. At a rotation speed above 5 Hz we obtain ratio $CO:H_2 \approx 1:2$, mostly common for the production of alcohols. At a rotation speed of 2–4 Hz we obtain ratio $CO:H_2 \approx 1:3$, mostly common for the production of hydrocarbons. The final result of the research can be applied even when creating a production for obtaining a gasoline fraction using the method of Fischer-Tropsch based on the process of aerosol nanocatalysis in a vibro boiling layer [20]. Thus, control over speed of rotation can adjust the ratio of $CO:H_2$ in the synthesis-gas depending on the needs of a particular production.

6. Discussion of results of studying the impact of the intensity of mechanochemical activation

In the course of studying the influence of the intensity of mechanochemical activation on the process of steam conversion of coal we modeled two modes:

1) with a large excess of coal ($C:H_2O = 5.5:1$) in the reactor (Table 1);

2) with a relatively small amount of coal ($C:H_2O = 1:0.87$) in order to intensify the mechanochemical activation (Table 2).

In the absence of reactor rotation, we observed a lower output of the products of conversion; this applies to all substances being obtained. That is, rotation of the reactor has a positive effect on the course of the process.

The number of collisions between a catalyst and a raw material increases due to the mechanical action. Rotating the reactor not only increases the efficiency of the use of a catalyst, but the agitation of a coal powder occurs. Coal particles are additionally crushed; the fraction of coal is brought to the dust-like state.

Tables 1, 2 show that changing the intensity of mechanochemical activation from 1 to 7 revolutions per second can enable control over the composition of conversion gases, thereby changing the amount of different products in different directions. The outputs of all the substances increase with an increase in the speed of reactor rotation to 3 Hz, followed by a decline afterwards. This is explained by the following. Increasing the speed of rotation leads to pressing the catalytic system and raw materials against the walls of the cylindrical reactor by centrifugal force and the rotation makes no further sense.

Thus, at 3 Hz, there is the biggest yield of targeted substances. For example, the output of hydrogen at 1 Hz amounted to 4.56 %, while at 3 Hz it increased to 11.73 % (Fig. 2). That is, it increased by 7.17 percentage points or by 2.57 times. Similar behavior was demonstrated by the yield of CO. At 1 Hz, its output totaled 3.37 %, and at 3 Hz it increased to 5.74 % (an increase of 2.37 percentage points or by 70.33 %).

Upon further increase in the intensity of mechanochemical activation we see the expected reduction: hydrogen yield – to 5.89 %, and carbon monoxide to 3.36 % (Table 1). That is, a decrease by 49.79 % and 41.46 %, respectively. The same trend can be observed under the mode with a shortage of coal (Table 2). Hence, we can conclude that it is advisable to maintain the process at the reactor rotation speed in the range from 2 to 4 Hz (3 Hz is optimal).

Obtaining the targeted substances is also accompanied by the formation of undesired products, such as hydrogen sulfide, methane, carbon monoxide and, in smaller quantities, ethane and ethylene (Tables 1, 2). The biggest yields of H_2S and CO_2 have also been registered at a speed of 3 Hz, both under the mode of studying with an excess of coal and at a relatively small amount of it (Fig. 3).

The composition of conversion gases given in Tables 1, 2 is explained by the conditions for conducting the process and the composition of starting raw materials. Namely: a high yield of hydrogen sulfide is due to the respective level of sulfur content in the examined samples of stone coal. It should be noted, however, that with an increasing intensity of the mechanochemical activation from 1 to 3 rotations per second, the yield of hydrogen changes at a higher increment compared with hydrogen sulfide. This is due to a certain chemistry of the process. Its special feature is an increase in the proportion of chemical reactions with the evolution of hydrogen at an increase in the intensity of mechanochemical activation.

The difference between the yields of products at different loads of coal and at a different water feed rate (Tables 1, 2) is due to the influence of change in the molar ratio of used raw materials on the change in shares of certain reactions in the total number of reactions that proceed in a given process.

Next, consider a change in the ratio of $CO:H_2$ under modes with a different load coal and at a different water feed rate: $C:H_2O = 0.87:1$ and $C:H_2O = 5.5:1$. In this case, we observe the mode of intensity of mechanochemical activation, in which we registered practical stability at the ratio of targeted products $CO:H_2$ (Fig. 4). Thus, in the speed range of 2–4 Hz, the ratio $CO:H_2$ is from 1:1.99 1:2.10 under the study mode with an excess of carbon (Table 1).

The value of the ratio $CO:H_2$ (1:1.99–1:2.10) under the study mode with an excess of carbon (Table 1) can be compared to the parameters of the process for obtaining methanol or other alcohols. In this industrial process, they apply the ratio $CO:H_2 \approx 1:2$. The ratio $CO:H_2 = 1:2$ is also used to obtain the products of oxysynthesis. The ratio $CO:H_2 = 1:1.19$, which we obtained under the mode with an excess of carbon (Table 1) is applied in the industry when deriving esters (1:1–1:1.2) [21].

The sum of the yields of CO and H_2, that is, a mix of the targeted products in a given process, increases from 7.93 to 17.47 % by volume at a change in the speed of reactor rotation from 1 to 3 Hz under the mode with an excess of coal. Under the mode with a shortage of coal the sum of the yields of H_2 and CO increases from 7.23 to 14.95 % by volume. That is, when designing the industrial production of methanol, it is possible to use the ratio $CO:H_2$ (1:1.99–1:2.10) and the sum of the outputs of H_2 and CO of 17.47 % by volume, which is achieved at a speed of 3 Hz and an excess of carbon.

The earlier studies into the process of obtaining hydrocarbons by the method of Fisher-Tropsch based on the process of aerosol nanocatalysis in a vibro-liquefied layer at 1 bar showed optimal modes at the starting ratio of synthesis-gas: $CO:H_2 \approx 1:3$ and 6 Hz; $CO:H_2 \approx 1:2$ and 4 Hz. It follows that obtaining such a ratio is possible through the steam conversion of coal in the catalyst aerosol in a rotating reactor at ratio $C:H_2O \approx 0.87:1$, 1 bar, and 2–4 Hz (Fig. 4) [20].

The preliminary results obtained indicate the possibility of conducting the process of steam conversion under conditions of the aerosol nanocatalysis technology. It is clear that the process is complicated while technological conditions have specific control parameters.

When compared with the analogue process of steam conversion of methane, which proceeds at 800–900 °C and 2–2.5 bars, the examined process of steam coal conversion consistently runs at 700–750 °C and 1 bar. It can also be managed additionally regulation by means of rotation speed, which gives it a wider application.

In the further determining the optimal mode for the course of the process of steam conversion of coal, it would be necessary to examine the concentration and composition of the catalyst and to extend the interval for the ratio of starting substances.

7. Conclusions

1. A scheme of the laboratory installation was prepared to study the impact of the intensity of mechanochemical activation on the course of the process of steam conversion of stone coal. Specifically: we improved the node that enables rotation of the reactor, replaced the motor and laboratory transformer. That made it possible to change the speed of rotation of the reactor in a wider range.

2. The results obtained show the possibility of the course of the progress under conditions of the aerosol nanocatalysis technology. The composition of conversion gases and the ratios of $CO:H_2$ can be controlled by means of the reactor rotation speed. Thus, a change in the intensity of mechanochemical activation can help obtain the ratios of products at 1 bar depending on the needs of a particular production.

3. When considering the impact of the intensity of mechanochemical activation on the yield of targeted products of the process of steam conversion of coal, we can conclude that it is advisable to maintain the process at a speed of rotation of the reactor in the range from 2 to 4 Hz (3 Hz is optimal). The mode with an excess of carbon, temperature 750 °C, the speed of rotation 2–4 Hz, in which the ratio $CO:H_2$ is from 1:1.99 to 1:2.10, can be used for the production of alcohols, namely methanol. The mode with an excess of carbon, a temperature of 750 °C, rotation speed not exceeding 1 Hz and the ratio $CO:H_2 = 1:1.19$ can be applied in the industry when obtaining esters (1:1–1:1.2). These are, however, only the preliminary results and conclusions; one must still consider the impact of other parameters in the process control. That would make it possible to approach the optimal mode for obtaining a specific product.

References

1. Obtaining synthesis-gas by the stone coal steam conversion using technology of aerosol nanocatalysis / Luhovskoi A., Glikin M., Kudryavtsev S., Glikina I. // Eastern-European Journal of Enterprise Technologies. 2017. Vol. 6, Issue 6 (90). P. 53–58. doi: https://doi.org/10.15587/1729-4061.2017.118396
2. Glikin M. A. Aerosol Catalysis // Theoretical Foundations of Chemical Technology. 1996. Vol. 30, Issue 4. P. 430–435.
3. Borshchev V. Ya. Equipment for grinding materials: crushers and mills: tutorial. Tambov: publishing house of Tambov State Technical University, 2004. 75 p.
4. Nanoscale materials in chemistry / K. J. Klabunde (Ed.). New York: F John. Wiley & Sons Inc., 2001. 807 p.
5. Products of Thermolysis of Tavantolgoy Black Coal / Kopylov N. I., Kaminsky U. D., Dugarzhav J., Avid B., Patrushev U. V. // Chemistry for Sustainable Development. 2015. Vol. 23, Issue 3. P. 235–246. doi: https://doi.org/10.15372/khur20150302
6. Composition and Physicochemical Properties of Coal Fractions with Different Densities / Fedorova N. I., Lyrshchikov S. U., Khitsova L. M., Ismagilov Z. R. // Chemistry for Sustainable Development. 2015. Vol. 23, Issue 2. P. 111–115. doi: https://doi.org/10.15372/khur20150201
7. Kopytov M. A., Golovko A. K. Cracking of a mixture of mechanically treated brown coal and petroleum residue // Solid Fuel Chemistry. 2013. Vol. 47, Issue 5. P. 26–30.
8. Bogomolov A. R., Shevyrev S. A., Alekseev M. V. Prospects for high-temperature gasification of coal and sludge // Thermal Engineering. 2013. Issue 2. P. 77–80. doi: https://doi.org/10.1134/s0040363612080024
9. Mongush G. R. Analysis of technical indicators of products of fractional separation of the kaa-khem's coal // Modern high technologies. 2017. Issue 11. P. 47–51. doi: https://doi.org/10.17513/snt.36843
10. Assessing possibility of burning zheronsky coal by Ust-Ilim CHP boiler units BKZ-420-140PT-2 / Kudryashov A., Kulagin N., Sinitskaya A., Bibikova I. // Proceedings of Irkutsk State Technical University. 2017. Vol. 21, Issue 2. P. 106–117. doi: https://doi.org/10.21285/1814-3520-2017-2-106-117

11. Vidian F., Novia, Suryatra A. Combustion of producer gas from gasification of south Sumatera lignite coal using CFD simulation // MATEC Web of Conferences. 2017. Vol. 101. P. 02015. doi: https://doi.org/10.1051/matecconf/201710102015
12. Carbon Shale Combustion in the Fluidized Bed Reactor / Olek M., Kandefer S., Kaniowski W., Żukowski W., Baron J. // Polish Journal of Chemical Technology. 2014. Vol. 16, Issue 2. doi: https://doi.org/10.2478/pjct-2014-0033
13. Influence of Environmentally Friendly and High-Efficiency Composite Additives on Pulverized Coal Combustion in Cement Industry / Wang Z., Wang S., Zhang Q., Fang Q., Chen W. // Journal of Combustion. 2016. Vol. 2016. P. 1–7. doi: https://doi.org/10.1155/2016/8205945
14. Formation of radicals in coal pyrolysis examined by electron spin resonance / Chang T., Guo Q., Hao H., Wu B., Yang Y. // AIP Advances. 2017. Vol. 7, Issue 9. P. 095303. doi: https://doi.org/10.1063/1.4986270
15. Kazawadi D., John G. R., King'ondu C. K. Experimental Investigation of Thermal Characteristics of Kiwira Coal Waste with Rice Husk Blends for Gasification // Journal of Energy. 2014. Vol. 2014. P. 1–8. doi: https://doi.org/10.1155/2014/562382
16. Advanced One-Dimensional Entrained-Flow Gasifier Model Considering Melting Phenomenon of Ash / Kim J., Oh H., Lee S., Yoon Y.-S. // Energies. 2018. Vol. 11, Issue 4. P. 1015. doi: https://doi.org/10.3390/en11041015
17. Cracking of crude oil using the technology of aerosol nanocatalysis (AnC) / Kudryavtsev S. A., Glikin M. A., Glikina I. M., Zaika R. G., Mamedov B. B. // Materials of the V international scientific and technical conference "Ukrkataliz-V". 2006. P. 9–12.
18. Nanotechnology. Basic science and emerging technnologies / Wilson M., Kannangara Geoff Smith K., Simmons M., Raguse B. Boca Raton: A CRC Press Co, 2002. 290 p. doi: https://doi.org/10.1201/9781420035230
19. Rapoport F. M., Il'inskaya A. A. Laboratory methods for obtaining pure gases. Moscow: Goskhimizdat, 1963. 420 p.
20. Synthesis of hydrocarbons using aerosol nanocatalysis technology. Effect of vibration and temperature on the process / Glikina I. M., Shershnev S. A., Glikin M. A., Zhitnitsky A. L. // Chemical promyslovosti of Ukraine. 2012. Issue 1 (108). P. 10–15.
21. Storch G., Golambik N., Anderson R. Synthesis of hydrocarbons from carbon monoxide and hydrogen / A. N. Bashkirov (Ed.). Moscow: Publishing. in. lit, 1954. 516 p.