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METAN KONVERSIYASI JARAYONIDA TURLI XIL MEMBRANALI REAKTORLARNING KATALIZATORGA TA'SIRINI O'RGANISH

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Annotatsiya. Bugungi kunda dunyoda metandan bir bosqichda sintez-gaz olish va uning asosida iqtisodiy samaradorligi bilan ajralib turadigan metanol hamda dimetil efirini ishlab chiqarish bo'yicha qator ishlar amalga oshirilmoqda. Metanning karbonat angidrid bilan konversiyasi uchun yuqori unumdorlik va selektivlikka ega bo'lgan arzon va faol katalizatorlarni tanlash, shuningdek, bug'li va karbonat angidridli konversiya yordamida sintez-gaz olish muhim ahamiyatga ega. Termodinamik asoslashni kompleks o'rganish hamda energiya va resurs tejovchi texnologiyalarni yaratishga asoslangan sintez-gaz olish jarayoni dolzarb masaladir.

Kalit so'zlar: Metan konversiyasi, membranali reaktor, metanning bug'li konversiyasi (SMR), metanning quruq (karbonat angidridli) konversiyasi (DRM), sintez-gaz, nikel asosli katalizator, vodorodga nisbatan selektiv membrana, jarayon intensifikatsiyasi.

Аннотация. На сегодняшний день во всем мире проведен ряд работ по получению синтез-газа из метана в одну стадию и производству на его основе метанола и диметилового эфира, отличающихся экономической эффективностью. Большое значение имеет подбор недорогих и активных катализаторов с высокой производительностью и селективностью для углекислотной конверсии метана, а также получение синтез-газа путем паровой и углекислотной конверсии. Процесс извлечения синтез-газа на основе комплексного изучения термодинамического обоснования и создания энерго- и ресурсосберегающих технологий является актуальной задачей.

Ключевые слова: Конверсия метана, мембранный реактор, паровая конверсия метана (SMR), углекислотная (сухая) конверсия метана (DRM),

синтез-газ, никелевый катализатор, водородселективная мембрана, интенсификация процесса.

Abstract. To date, a number of works have been carried out in the world on obtaining synthesis gas from methane in one stage and on its basis methanol and dimethyl ether, distinguished by economic efficiency. Selection of low-cost and active catalysts with high productivity and selectivity for carbonate conversion of methane with carbon dioxide and obtaining synthesis gas from steam and conversion of carbon dioxide and methane into carbon dioxide with the participation of carbonate conversion and steam and The process of extracting synthesis gas from carbonate conversion, based on a comprehensive study of its thermodynamic justification and the creation of energy- and resource-saving technologies, is of great importance.

Keywords: Methane conversion, Membrane reactor, Steam methane reforming (SMR), Dry reforming of methane (DRM), Synthesis gas (Syngas), Nickel-based catalyst, Hydrogen-selective membrane, Process intensification

INTRODUCTION.

Methane conversion into synthesis gas (syngas), a mixture of hydrogen and carbon monoxide, is one of the most important technological routes in modern chemical industry. Syngas serves as a key intermediate for the production of methanol, dimethyl ether (DME), synthetic fuels, and numerous value-added chemicals. Industrially, syngas is mainly produced through steam methane reforming (SMR), dry reforming of methane (DRM), partial oxidation (POX), and autothermal reforming (ATR) processes. Among these, conventional tubular steam reformers remain dominant due to their technological maturity; however, they are characterized by high energy consumption, significant CO_2 emissions, and large reactor volumes [1]. Therefore, the development of intensified reactor systems capable of improving conversion, selectivity, and energy efficiency is a critical research direction.

Steam methane reforming is a highly endothermic reaction carried out over nickel-based catalysts at temperatures of 800–900 °C in multitubular fixed-bed reactors heated by external furnaces [2]. Although SMR offers high hydrogen yield, it requires substantial heat input and suffers from thermodynamic limitations at moderate temperatures. Dry reforming of methane, which utilizes carbon dioxide as a reactant ($CH_4 + CO_2 \rightarrow 2CO + 2H_2$), provides an attractive route for CO_2 utilization and greenhouse gas mitigation [3]. However, DRM is accompanied by severe catalyst deactivation due to carbon deposition and sintering at elevated temperatures. The selection of stable and low-cost catalysts, particularly Ni-based systems modified with promoters or supported on thermally stable oxides, is therefore essential [4].

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Membrane reactor technology has emerged as a promising approach for process intensification in methane conversion. By integrating catalytic reaction and selective separation within a single unit, membrane reactors can shift thermodynamic equilibrium toward higher conversion according to Le Chatelier's principle. Hydrogen-permeable membranes, such as palladium-based alloys or ceramic proton-conducting membranes, selectively remove hydrogen from the reaction zone, enhancing methane conversion and suppressing side reactions [5]. Similarly, oxygen-permeable membranes enable distributed oxygen supply in oxidative reforming, eliminating the need for external oxygen feed and improving safety and process efficiency [6].

Different types of membrane reactors—dense metallic membranes, mixed ionic–electronic conducting (MIEC) ceramic membranes, and porous inorganic membranes—exert distinct influences on catalytic performance. In hydrogen-selective membrane reactors for SMR or DRM, continuous hydrogen extraction reduces partial pressure, mitigates coke formation, and stabilizes nickel catalysts [7]. In oxygen-permeable membrane reactors applied to partial oxidation or autothermal reforming, controlled oxygen flux ensures uniform temperature distribution and prevents hot spots that may deactivate catalysts [8]. Thus, the interaction between membrane characteristics (permeability, selectivity, thermal stability) and catalyst properties (activity, dispersion, resistance to coking) plays a decisive role in reactor efficiency.

Technologically, membrane reactors may be designed as tubular modules, planar configurations, or integrated packed-bed systems. The coupling of catalytic bed geometry with membrane surface area determines mass transfer rates and overall reactor productivity. Compared to conventional fixed-bed reformers, membrane reactors enable lower operating temperatures, reduced reactor size, and improved energy efficiency. Moreover, their integration into downstream processes—such as methanol and dimethyl ether synthesis—facilitates compact and resource-saving process schemes.

Results and Discussion. A distributor reactor used for catalytic and non-catalytic thermal conversion of methane using a catalyst with high catalytic activity and efficiency. In reactors of this type, used for thermal conversion of methane in the presence of a catalyst with high catalytic activity and efficiency, a membrane is usually used to maintain the minimum required concentration of one of the reactants (a substance included in the process) in the process mixture, thereby preventing additional processes.

Figure 1 shows various types of flow charts for feeding steam and methane gas into reactors designed for the conversion of carbon monoxide (IV) in the process of converting methane into carbon monoxide (IV).

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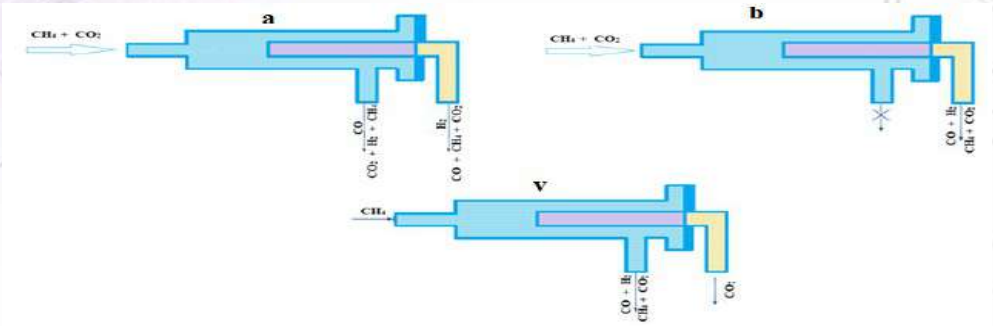


Fig. 1. Schemes of different types of membrane reactors designed for processing methane into water vapor and carbon dioxide: a-extractor , b-contactor , v -distributor

The Extractor type methane conversion with water vapor and carbon monoxide (IV) is suitable for methane conversion with carbonate under the influence of carbon monoxide (IV) and steam-carbonate conversion with water vapor and carbon monoxide (IV) in the developed membrane reactor (Fig. 1.a), the pre-mixed feedstock entering the process is fed into the reactor, designed for the conversion of water vapor, methane and carbon monoxide (IV), where the catalytic process and gas separation take place, then the products of the process, i.e. the exhaust gas and hydrogen from the reactor, designed for the conversion of water vapor, methane and carbon monoxide (IV), are released through two channels: standing channel (gases that have not passed through the membrane) and permeate channel (gases that have passed through the membrane).

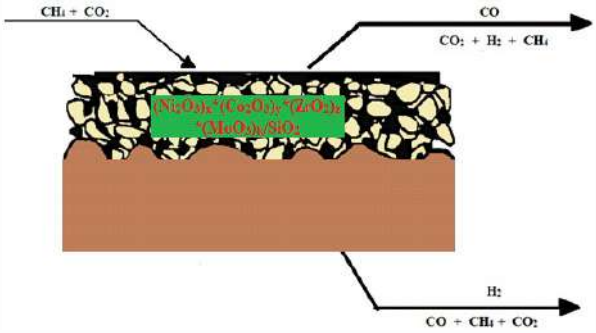


Fig. 2. Operating principle of a membrane catalyst in a membrane reactor designed for catalytic conversion of " extractor " methane in the presence of water vapor and carbon dioxide and under the influence of catalysts.

Fig. 2 shows the conversion rates of methane and carbon dioxide and the hydrogen specificity of the process of steam and carbon oxide (IV) oxide conversion (reforming) of methane during catalytic conversion of methane in the presence of water vapor and carbon dioxide and under the influence of catalysts. When carried out in a designed membrane reactor (CH_4:CO2=1:1), the dependence of the initial gas mixture on the flow rate is shown.

Fig. 3 shows the degree of change in methane and carbon dioxide gases, as well as the dependence on the volumetric flow rate of the initial gas mixture

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(CH_4:CO_2=1:1) of the specificity for hydrogen in the "contactor". A membrane-water process (880°C and 910°C) is described in a reactor designed for catalytic conversion in the presence of steam and carbon dioxide and under the influence of catalysts.

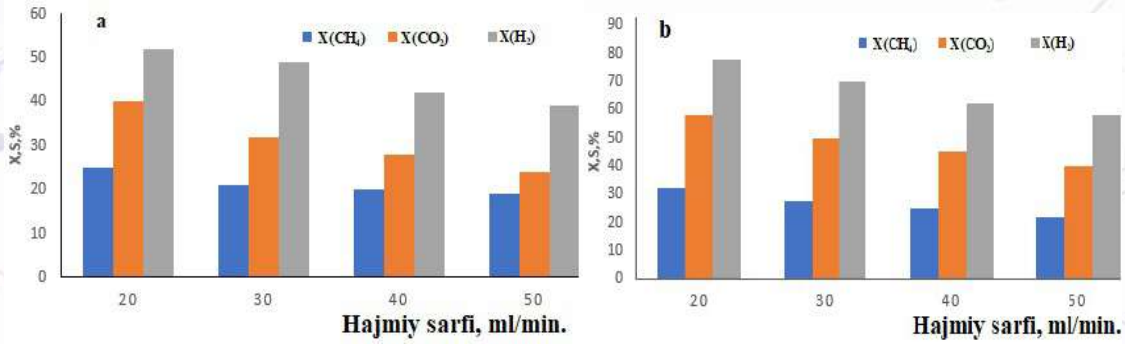


Fig. 3. Dependence of the conversion rate of methane and carbon dioxide on the consumption of the initial mixture for the process of methane conversion with carbon monoxide (IV) in a contactor-type reactor, at different temperatures: a-880°C, b-910°C.

The composition of the conversion products, i.e. carbon dioxide and hydrogen, is presented in Table 1 below.

Table 1

The composition of the conversion products is carbon dioxide and hydrogen.

T, ^{0}C	Input, ml/min			Product composition, %				
	CH_4	CO_2	general	CH_4	CO_2	CO	H_2	N_2
880	25	25	50	37,37	35.58	18,14	6.17	2.8
	20	20	40	36.24	32.79	20.77	7.39	2.14
	15	15	30	35.55	30.04	24.15	9.05	1.97
	10	10	20	32.92	26.38	28.36	11.61	2.09
910	25	25	50	34.62	27.31	27.35	11.62	0.66
	20	20	40	33.02	24.51	29.96	13.37	0.67
	15	15	30	30.8	21.08	33.13	16.37	0.73
	10	10	20	27.11	17.47	36.46	20.72	0.87

This type is intended for catalytic conversion of methane in the presence of water vapor and carbon dioxide and under the influence of catalysts, for the conversion of methane with carbonate under the action of carbon monoxide (IV) and steam-carbonate conversion in the presence of water vapor and carbon monoxide (IV) consideration of the advantages of using the developed membrane reactor, only the main parameters of the conversion (reforming) process of methane with water vapor and carbon monoxide (IV) catalytic conversion of methane in the presence of water vapor and carbon dioxide and under the

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influence of catalysts. It is possible to compare with analogs the indicators for other types of reactors intended for n.p.

Fig. 4 shows the principle of using a membrane catalyst in a membrane reactor designed for the catalytic conversion of methane with carbon monoxide (IV) in the presence of water vapor and carbon dioxide and under the influence of catalysts. The raw materials (inputs) are fed from different sides of the membrane catalyst, mixed and interact in the catalyst, and the process products - carbon dioxide and hydrogen - are obtained from the methane feed.

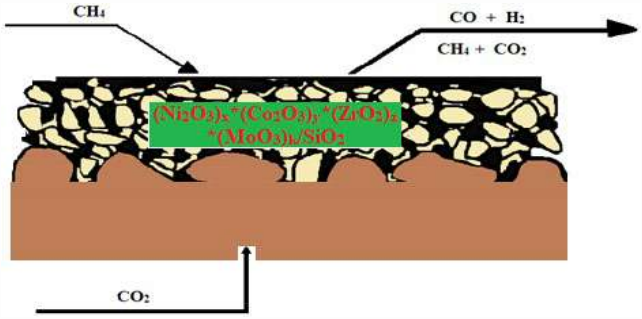


Fig. 4. Operating principle of a membrane catalyst in a membrane reactor designed for catalytic conversion of distributor-class methane in the presence of water vapor and carbon dioxide and under the influence of catalysts.

Class "Distributor" designed for catalytic conversion of methane in the presence of water vapor and carbon dioxide and under the influence of catalysts, gasified methane under the influence of carbon monoxide (IV) and steam carbonate in the presence of water vapor and carbon (IV), oxide conversion (reforming) of methane with carbon monoxide (IV) in a membrane reactor designed for conversion.

Table 2

The conversion products are carbon dioxide and hydrogen content.

T,^{0} with	Input, ml/min			Product composition, %				
	CH_4	CO_2	general	CH_4	CO_2	CO	H_2	N_2
880	25	25	50	36.32	37.09	16.34	8.62	2.04
	20	20	40	26.15	30.84	22.36	20.31	1.74
	15	15	30	12.7	18.36	33.15	36,38	1.77
	10	10	20	8.67	12.56	37.46	42.31	2.08
910	25	25	50	24.11	31.58	23.04	22.49	1.22
	20	20	40	9.44	16.59	33.07	42.68	1.14
	15	15	30	6.02	12.56	35.29	47.55	1.38
	10	10	20	4.49	10.72	37.17	48.68	1.9

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In the process of methane conversion with carbon monoxide (IV), the "distributor" type is designed for the catalytic conversion of methane in the presence of water vapor and carbon dioxide and under the influence of catalysts into carbonated and water vapor under the influence of carbon monoxide (IV) and carbon monoxide (The principle of using a membrane reactor designed for steam-carbonate conversion in the presence of IV) oxide is explained in Fig. 5.

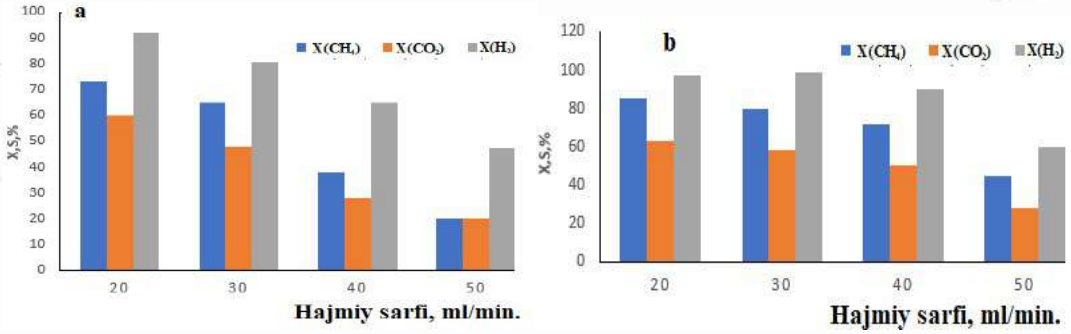


Fig. 5. Methane into carbon in a membrane reactor designed for catalytic conversion (reforming) of methane and carbon dioxide in the presence of water vapor and carbon dioxide and under the influence of distributor class catalysts at different temperatures of hydrogen (IV) specificity, flow rate dependence of the initial mixture for the oxide conversion process: a - 880°C, b - 910°C

Membrane reactors designed for carbonized conversion of methane under the influence of carbon monoxide (IV) and water vapor and steam-carbonate conversion in the presence of carbon monoxide (IV), extractor, distribution and contactor membrane reactors. Possibilities of use in synthesis gas. Extraction processes with carbonate conversion have been studied and it has been proven that the process is carried out in a membrane apparatus.

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