MUHANDISLIK & IQTISODIYOT

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05.01.00 – Axborot texnologiyalari, boshqaruv va kompyuter grafikasi
05.01.01 – Muhandislik geometriyasi va kompyuter grafikasi. Audio va video texnologiyalari
05.01.02 – Tizimli tahlil, boshqaruv va axborotni qayta ishlash
05.01.03 – Informatikaning nazariy asoslari
05.01.04 – Hisoblash mashinalari, majmualari va kompyuter tarmoqlarining matematik va dasturiy ta'minoti
05.01.05 – Axborotlarni himoyalash usullari va tizimlari. Axborot xavfsizligi
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05.02.00 – Mashinasozlik va mashinashunoslik
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05.04.01 – Telekommunikasiya va kompyuter tizimlari, telekommunikasiya tarmoqlari va qurilmalari. Axborotlarni taqsimlash
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05.08.06 – "G'ildirakli va gusenisali mashinalar va ularni ishlatish" (texnika fanlari)
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05.09.04 – Suv ta'minoti. Kanalizatsiya. Suv havzalarini muhofazalovchi qurilish tizimlari
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08.00.06 – Ekonometrika va statistika
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08.00.15 – Tadbirkorlik va kichik biznes iqtisodiyoti
08.00.16 – Raqamli iqtisodiyot va xalqaro raqamli integratsiya
08.00.17 – Turizm va mehmonxona faoliyati

Ma'lumot uchun, OAK Rayosatining 2024-yil 28-avgustdagi 360/5-son qarori bilan "Dissertatsiyalar asosiy ilmiy natijalarini chop etishga tavsiya etilgan milliy ilmiy nashrlar ro'yxati"ga texnika va iqtisodiyot fanlari bo'yicha "Muhandislik va iqtisodiyot" jurnali ro'yxatga kiritilgan.

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STUDY OF THE INFLUENCE OF MEMBRANE REACTOR ON METHANE CONVERSION WITH WATER VAPOR AND CARBON OXIDE (IV)

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Abstract: A number of studies have been carried out worldwide on the one-stage production of synthesis gas from methane, as well as methanol and dimethyl ether based on it, which are characterized by high economic efficiency. The selection of low-cost and active catalysts with high productivity and selectivity for the carbonate conversion of methane in the presence of carbon dioxide and water vapor for synthesis gas production is of great importance. In addition, the development of energy- and resource-saving technologies based on a comprehensive thermodynamic study of methane and carbon dioxide carbonate conversion processes in the presence of water vapor remains highly relevant.

Keywords: synthesis gas, methane, carbonate conversion, carbon dioxide, water vapor, catalyst, methanol, dimethyl ether, thermodynamic analysis, energy-saving technology.

Annotatsiya: Jahonda metandan bir bosqichda sintez-gaz olish hamda uning asosida iqtisodiy samaradorligi yuqori bo'lgan metanol va dimetil efir ishlab chiqarish bo'yicha ko'plab tadqiqotlar olib borilgan. Metanning karbonat konversiyasini karbonat angidrid va suv bug'i ishtirokida amalga oshirish, sintez-gaz olish uchun yuqori unumdorlik va selektivlikka ega, arzon hamda faol katalizatorlarni tanlash muhim ahamiyat kasb etadi. Shuningdek, karbonat konversiyasi va suv bug'i ishtirokida karbonat angidrid hamda metanning konversiyasi jarayonlarini termodinamik jihatdan kompleks tadqiq etish asosida energiya va resurs tejamkor texnologiyalarni yaratish dolzarb hisoblanadi.

Kalit so'zlar: sintez-gaz, metan, karbonat konversiyasi, karbonat angidrid, suv bug'i, katalizator, metanol, dimetil efir, termodinamik tahlil, energiya tejamkor texnologiya.

Аннотация: В мире проведено большое количество исследований по получению синтез-газа из метана в одну стадию, а также метанола и диметилового эфира на его основе, отличающихся высокой экономической эффективностью. Важное значение имеет выбор недорогих и активных катализаторов с высокой производительностью и селективностью для карбонатной конверсии метана с участием диоксида углерода и водяного пара с целью получения синтез-газа. Кроме того, актуальным является создание энерго- и ресурсосберегающих технологий на основе комплексного термодинамического исследования процессов карбонатной конверсии метана и диоксида углерода с участием водяного пара.

Ключевые слова: синтез-газ, метан, карбонатная конверсия, диоксид углерода, водяной пар, катализатор, метанол, диметиловый эфир, термодинамический анализ, энергосберегающая технология.

INTRODUCTION

Methane is the main component of natural gas and represents one of the most important raw materials for the production of synthesis gas (syngas), which consists primarily of hydrogen (H□) and carbon monoxide (CO). Syngas serves as a fundamental intermediate in the chemical industry and is widely used for the production of methanol, dimethyl ether (DME), ammonia, and synthetic liquid fuels. In recent decades, significant attention has been given to the development of efficient technologies for methane conversion due to the increasing demand for hydrogen and environmentally friendly fuels. Conventional technologies for syngas production are mainly based on steam methane reforming (SMR), dry reforming with carbon dioxide (DRM), partial oxidation (POX), and autothermal reforming (ATR). These processes are typically carried out in tubular catalytic reactors operating at high temperatures (700–900 °C) and require significant energy input, which affects the overall economic efficiency of the process [1].

Steam methane reforming is currently the most widely applied industrial technology for hydrogen and syngas production. In this process, methane reacts with water vapor in the presence of nickel-based catalysts to produce hydrogen and carbon monoxide according to the reaction $CH_4 + H_2O \rightarrow CO + 3H_2$. The reaction is strongly endothermic and therefore requires high operating temperatures and efficient heat transfer systems within reforming furnaces. Industrial SMR units typically consist of multi-tubular reactors placed inside large furnaces where heat is supplied externally through combustion of fuel gases. Although this technology is well established, it suffers from several limitations including high energy consumption, large equipment size, and thermodynamic equilibrium restrictions that limit methane conversion [2].

Another promising route for methane utilization is the dry reforming process, in which methane reacts with carbon dioxide ($CH_4 + CO_2 \rightarrow 2CO + 2H_2$). This technology is attractive because it simultaneously converts two greenhouse gases—methane and carbon dioxide—into valuable syngas. However, dry reforming reactions occur at high temperatures and often lead to catalyst deactivation due to carbon deposition and sintering of active metal particles. Therefore, the development of stable catalysts and advanced reactor designs is necessary to improve process efficiency and catalyst lifetime [3].

In recent years, membrane reactor technology has emerged as a promising solution for improving methane conversion processes. A membrane reactor integrates catalytic reaction and selective separation in a single unit, allowing continuous removal of one of the reaction products from the reaction zone. According to Le Chatelier's principle, removal of hydrogen through a hydrogen-selective membrane shifts the reaction equilibrium toward higher methane conversion. This approach enables operation at lower temperatures while achieving higher yields compared to conventional fixed-bed reactors [4].

Membrane reactors can be designed in various configurations such as tubular membrane reactors, packed-bed membrane reactors, and catalytic membrane modules. In these systems, selective membranes—often made of palladium alloys or ceramic materials—allow hydrogen permeation while retaining other gases within the reaction zone. The integration of membrane separation with catalytic reforming significantly improves mass transfer, enhances catalyst utilization, and reduces reactor volume. In addition, membrane-assisted reforming processes can lead to more compact and energy-efficient technological schemes for hydrogen and syngas production [5].

The combined conversion of methane with water vapor and carbon dioxide represents an important technological approach that integrates the advantages of both steam reforming and dry reforming processes. This combined reforming process improves the H_2/CO ratio in the produced synthesis gas, making it suitable for downstream chemical processes such as methanol synthesis and Fischer–Tropsch fuel production. The efficiency of such systems strongly depends on the interaction between catalyst properties, reactor design, and membrane characteristics including permeability, selectivity, and thermal stability [6].

REVIEW OF LITERATURE ON THE SUBJECT

The processes of methane conversion and membrane reactor technology have become one of the most important scientific directions in recent years in terms of improving the efficiency of hydrogen and synthesis gas production. In particular, steam and carbon dioxide reforming of methane have been extensively investigated due to problems associated with high energy consumption, catalyst activity, and product selectivity. In this field, the studies conducted by Jens Rostrup-Nielsen, Jens Sehested, and Jens K. Nørskov comprehensively analyzed the thermodynamic and kinetic aspects of steam and CO_2 reforming reactions of methane. The authors demonstrated that high operating temperature, catalyst stability, and carbon deposition are the major challenges in hydrogen and synthesis gas production processes, while also confirming the effectiveness of nickel-based catalysts [1].

The research carried out by David L. Trimm and Zehra I. Onsan focused on the development of compact fuel conversion systems for hydrogen-fuel-cell-driven vehicles. Their study emphasized that optimization of heat transfer and catalytic systems is essential for achieving high efficiency in methane steam conversion processes. The researchers also noted that the application of membrane technologies in compact reforming reactors shifts the reaction equilibrium toward hydrogen formation [2].

The mechanisms of CO_2 reforming were extensively investigated by Matthew C. J. Bradford and Mark A. Vannice, who evaluated the reaction between methane and carbon dioxide as a promising environmentally friendly technology. The authors highlighted that CO_2 reforming allows simultaneous utilization of two greenhouse gases. However, they also identified coke formation on the catalyst surface and catalyst deactivation as the major limiting factors of the process [3].

In the field of membrane reactors, the studies conducted by Fausto Gallucci and Angelo Basile investigated steam reforming systems based on palladium-silver (Pd-Ag) membranes. Their results demonstrated that selective removal of hydrogen from the reaction medium shifts the chemical equilibrium toward product formation and significantly increases methane conversion. The researchers concluded that membrane reactors provide higher

hydrogen yield, lower energy consumption, and more compact reactor design compared with conventional reactors [4].

The studies of Joko Sunarso, Stefan Baumann, José Manuel Serra and co-authors on mixed ionic-electronic conducting membranes made an important contribution to the development of next-generation membrane technologies. They analyzed the high-temperature stability and selectivity of membranes used for oxygen separation and demonstrated that such systems can effectively control the oxidizing environment in reforming processes [5].

Research by Nathan W. Ockwig and Todd M. Nenoff on hydrogen separation membranes compared the technological characteristics of metallic, ceramic, and composite membranes. The authors concluded that high selectivity and permeability of membranes are among the key factors for improving the efficiency of reforming systems. In particular, palladium-based membranes were identified as one of the most promising materials for obtaining high-purity hydrogen [6].

Overall, the existing scientific literature demonstrates the growing importance of membrane reactors in methane conversion processes. Membrane technologies provide significant advantages in controlling reaction equilibrium, increasing hydrogen yield, reducing energy consumption, and improving environmental sustainability. Therefore, membrane reactors are considered one of the most promising modern technologies for efficient synthesis gas and hydrogen production.

RESEARCH METHODOLOGY

In a reactor designed for membrane reforming of methane with steam and carbon monoxide (IV), both the chemical process and the membrane process occur simultaneously. In recent years, many methods have been proposed to use membranes in combination with the chemical process to accelerate the overall process. Depending on the function of the membrane in a membrane reactor designed for reforming methane with steam and carbon monoxide (IV), methane intended for reforming methane with steam and carbon monoxide (IV) is processed into carbonized and membrane reactors. Designed for steam-carbonate reforming in the presence of water vapor and carbon monoxide (IV), are divided into three main types:

In the extractor, the membrane selectively separates one or more products of the process, i.e. carbon dioxide and hydrogen, from the mixture of the substance undergoing the initial reaction and the substances formed as a result of the process;

In the distributor, the membrane controls the addition of the primary reactant to the mixture of primary reactant and process product;

The contactor membrane accelerates the interaction of the initially reacting substances with the catalyst.

ANALYSIS AND RESULTS

The productivity of the membrane reactor designed for the conversion of methane with steam and carbon monoxide (IV) into carbonate under the influence of carbon monoxide (IV) and steam-carbonate reforming in the presence of water vapor and carbon monoxide (IV) The most common type operates on the extractor principle. In one of the reactors designed for the conversion of methane into steam and carbon monoxide (IV), only one of the products can pass through the membrane - carbon dioxide and hydrogen, and selective separation occurs, and in others - retention of the catalyst occurs, that is, the membrane is permeable to all components of the mixture of substances formed as a result of the process, except for the catalyst.

One of the components formed during a chemical process is selectively removed from a mixture of the substance undergoing the initial reaction and the substance formed as a result of the process. If one of the products - carbon dioxide and hydrogen - acts as an inhibitor, its removal can significantly increase the productivity of a reactor designed to convert methane into steam and carbon monoxide (IV). Also, a membrane reactor designed to convert this type of methane with steam and carbon monoxide (IV) allows for an increase in the concentration of the starting materials.

Reactors of this type are designed for the conversion of methane into water vapor and carbon oxide (IV) in the form of a contactor with a forced flow through the membrane, that is, a flow-catalytic methane designed for the conversion of water vapor and carbon oxide (IV) into carbon (It is interesting to use it as a membrane reactor and an interphase contactor for steam-carbonate conversion in the presence of carbonate vapor and water under the influence of IV) oxide and carbon oxide (IV).

Methane membrane reactor designed for the conversion of methane under the action of water vapor and carbon dioxide in the presence of catalysts into carbonate under the action of carbon monoxide (IV) and steam-carbonate conversion under the action of water vapor and carbon (IV) oxide in this type, the initially mixed reagents

are passed through a special porous catalytic membrane. The function of the reactor designed for the conversion of methane under the action of steam and carbon dioxide in the presence of catalysts is to provide the reaction space with a short controlled exposure time and high catalytic activity. The purpose of using reactors designed for the conversion of methane with a flow-through catalytic membrane under the influence of water vapor and carbon dioxide in the presence of catalysts is to achieve complete conversion in the shortest possible time and in the smallest reaction space, or for this process the catalyst with the substance undergoing the initial reaction must achieve maximum specificity due to a narrow distribution of the exposure time between the active centers.

The process of methane conversion to carbon monoxide (IV) was compared with the operational characteristics of their material in a reactor designed for the conversion of methane to water vapor and carbon monoxide (IV) in membrane catalysts in a contactor and distributor. As the main parameters of the process of catalytic conversion of methane with carbon monoxide (IV), water vapor and carbon monoxide (IV) conversion (reforming) of methane are the main indicators of the change in the concentration of components in the products, i.e. carbon dioxide and hydrogen, the degree of change in gaseous substances entering the original process, and the ratio of the components of the mixture of hydrogen and thermal gas depending on the time of interaction of the substance entering the original process. reactions and the active center of the catalyst (Figure 1).

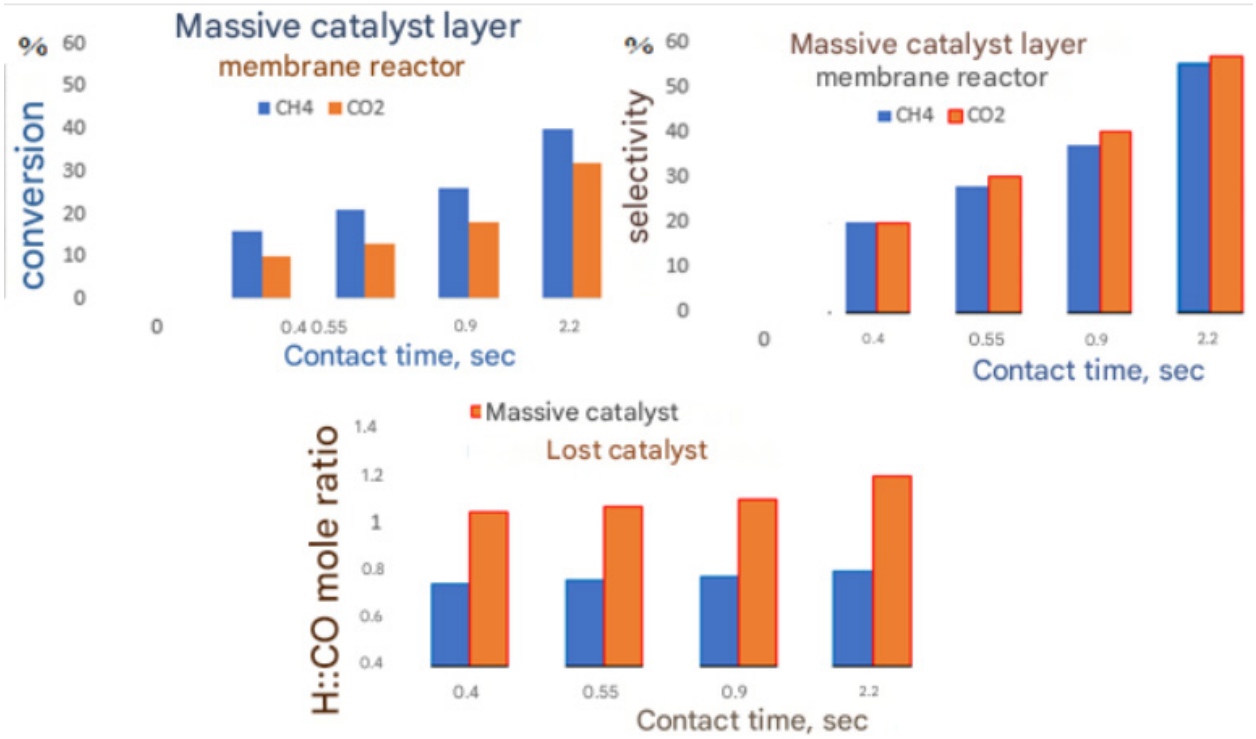

Figure 1. Comparison of Membrane Catalysts at 900°C in Methane Carbonate Conversion[2]

In this case, the structure of the membrane catalyst affects the degree of change and selectivity of the process of conversion (reforming) of methane with water vapor and carbon monoxide (IV).

Kinetic regularities of the process recorded under the conditions of a differential reactor (rate of change of the initial substances, kinetic model of the process, influence of various factors on the conversion rate and selection of the optimal process mode). The optimal conditions for carrying out the process were also studied (CH_4:H_2O:CO_2 = 1:1:0.4; P = 0.1 MPa; V_0 = 1000 h^{-1}; T = 900°C and τ_{kont} = 0.88 s).

CONCLUSIONS AND SUGGESTIONS

In conclusion, the use of membrane reactor technology significantly improves methane conversion with water vapor and carbon dioxide. The integration of catalytic reaction and selective hydrogen separation in one reactor increases methane conversion and enhances synthesis gas yield. Continuous hydrogen removal shifts the reaction equilibrium toward product formation, resulting in higher efficiency compared to conventional reactors. These results correspond to the objectives stated in the abstract, highlighting the importance of developing energy- and resource-efficient technologies for syngas production. The use of active catalysts together with membrane reactors improves reaction selectivity and stability. Therefore, membrane reactor systems represent a promising

technological approach for efficient synthesis gas production and further chemical processes such as methanol and dimethyl ether synthesis.

List of used literature:

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