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# Prospects for utilizing natural gas from the Anabai gas field for synthesis gas production via dry reforming of methane

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**Abstract.** Dry reforming of methane (DRM) is a promising approach for producing synthesis gas, a mixture of hydrogen and carbon monoxide, which serves as a valuable intermediate for energy and chemical applications. In the context of the global energy transition, hydrogen is considered a potential low-carbon energy carrier, while DRM enables the simultaneous utilization of methane and carbon dioxide. This study aimed to assess the prospects of the Anabai gas field for converting produced natural gas into synthesis gas via the DRM reaction and to demonstrate the practical feasibility of methane conversion based on laboratory-scale experiments. To evaluate the potential of methane utilization, data on the methane content of natural gas from the Anabai field under surface and subsurface conditions were analyzed. Surface gas characteristics were determined using 56 wellhead samples from Famennian, Lower, Middle, and Upper Visean, as well as Serpukhovian deposits. Subsurface gas composition was assessed based on 102 samples from the Famennian, Tournaisian, and Visean–Serpukhovian stages. The results indicate a consistently high methane content across the studied stratigraphic horizons. Experimental DRM studies were carried out using a 20Co-10Mg-20Al catalyst synthesized by the self-propagating high-temperature synthesis (SHS) method. The catalytic performance was evaluated in terms of methane and carbon dioxide conversion, synthesis gas composition, and temperature dependence. Based on the experimental results, practical recommendations for implementing DRM at the Anabai gas field are proposed, and the prospects for integrating this technology into environmentally oriented energy production schemes are discussed.

***Keywords:*** *gas field, dry methane reforming, syngas, methane, hydrogen*.

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## 1. Introduction

Currently, humanity is facing increasingly urgent challenges related to the planet's future development. Intensive human activity and extensive industrial growth over recent decades have led to significant environmental degradation on a global scale. Anthropogenic factors play a significant role in climate change and the large-scale transformation of natural ecosystems. Issues such as greenhouse gas emissions, global warming, environmental pollution, biodiversity loss, soil degradation, and desertification have become widely recognized and discussed worldwide. These challenges are inherently global, as their consequences extend beyond national borders and impact societies and ecosystems worldwide.

In response to the growing environmental risks and their potential long-term impacts, governments and international organizations have undertaken a range of mitigation and sustainability-oriented initiatives. Environmental protection and sustainable development occupy a central position on the United Nations' agenda. In particular, in 2015, the UN General Assembly adopted the Sustainable Development Goals (SDGs), formulated as a comprehensive framework aimed at achieving balanced economic growth, social well-being, and environmental sustainability. Within this framework, the transition toward a more sustainable and resilient global energy system, commonly referred to as the energy transition, has been identified as one of the key pathways for reducing environmental pressures and ensuring long-term development. The concept of the energy transition refers to a profound structural transformation of the global energy sector as an integrated system. This transformation is driven by changes in the energy mix, including the increasing deployment of new and renewable energy sources, as well as a gradual reduction in the share of conventional fossil fuels in total global energy production.

From a historical perspective, the development of the global energy system can be divided into four primary stages of energy transition. The first stage is associated with the shift from the use of relatively inefficient but readily available biomass, primarily wood, to a more energy-dense fossil fuel – coal. This transition began in the second half of the nineteenth century, driven by rapid industrialization and the widespread adoption of steam engines, and is generally considered to have been completed by the beginning of the twentieth century. During this period, the share of coal in the global energy balance increased significantly, from marginal levels to approximately 50%.

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The second stage of the energy transition is characterized by the growing dominance of oil as a primary energy source. Its role increased substantially throughout the twentieth century, with oil accounting for approximately 3% of the global fuel balance in 1915 and rising to about 45% by 1975. The third stage corresponds to the widespread introduction of natural gas in both energy production and industrial applications. Unlike previous stages, this period is characterized by the absence of a single dominant energy resource and a more diversified energy structure.

The fourth stage of the energy transition has been underway since the early 2000s. It is characterized by the large-scale deployment of renewable energy sources and a gradual shift away from fossil fuels, specifically hydrocarbons. According to the International Energy Agency, this transition is expected to extend through the middle of the twenty-second century, with a projected completion around 2150. Thus, the present period can be regarded as an active phase of the fourth energy transition. In this context, the investigation of hydrogen production pathways derived from natural gas and methane, in particular, has become increasingly relevant as a potential component of a more sustainable and low-carbon energy system.

Dry reforming of methane (DRM) has been widely investigated as a sustainable pathway for the simultaneous conversion of two primary greenhouse gases, $CH_4$ and $CO_2$, into synthesis gas, which serves as a key intermediate for the production of fuels and value-added chemicals [1, 2]. Among the various catalytic systems explored, Ni- and Co-based catalysts have received considerable attention due to their high intrinsic activity and economic advantages over noble-metal catalysts [3, 4]. However, the practical deployment of these materials is still hindered by catalyst deactivation under severe DRM conditions, primarily caused by carbon deposition, metal sintering, and insufficient thermal stability.

To address these limitations, significant research efforts have focused on developing advanced catalyst preparation techniques and compositional modifications. In particular, solution combustion synthesis (SCS) and self-propagating high-temperature synthesis (SHS) have emerged as efficient and versatile methods for producing catalysts with highly dispersed active phases, strong metal-support interactions, and improved resistance to deactivation [5-7]. Catalysts prepared via these methods often exhibit enhanced redox properties and structural stability compared to conventionally synthesized materials, making them especially attractive for high-temperature DRM applications.

Further enhancement of catalytic performance has been achieved through the incorporation of promoter oxides and secondary metals. Rare-earth oxides, such as $CeO_2$ and $La_2O_3$, have been reported to improve oxygen mobility and facilitate the gasification of surface carbon species, thereby suppressing coke formation on Ni-based catalysts [8]. In addition, the introduction of transition metal promoters, including Mn, Mg, and Fe, has been shown to modify the acid–base characteristics and redox behavior of the catalyst surface, leading to improved catalytic activity, stability, and syngas selectivity in DRM reactions [9-11].

In parallel with Ni-based systems, increasing attention has been devoted to Co-based catalysts, which generally exhibit a lower tendency toward carbon formation. Recent studies have demonstrated that lanthanide-doped Co-Al catalysts prepared by SCS exhibit promising catalytic activity and stability in DRM, highlighting the potential of Co-Ce-Al and Co-La-Al formulations as viable alternatives to conventional Ni-containing catalysts [12, 13]. Overall, the existing body of literature confirms the high potential of Ni- and Co-based catalysts synthesized via combustion-based methods for DRM. Nevertheless, a comprehensive understanding of the interplay between catalyst composition, promoter selection, and synthesis parameters remains incomplete, emphasizing the need for further systematic and comparative investigations [1-13].

The purpose of this research work was to demonstrate the potential of the Anabai gas field in utilizing the extracted natural gas to convert it into synthesis gas through the DRM reaction, and to investigate and illustrate, using laboratory scientific experiments on DRM, the practical feasibility of obtaining synthesis gas from methane.

## 2. Materials and methods

### 2.1. Object of study and characteristics of the Anabai gas field

The object of this study is the Anabai gas field, which is currently under industrial exploitation and is characterized by a high methane content in the produced natural gas. This feature allows the field to be considered a promising source of methane for synthesis gas production via dry reforming of methane (DRM). The Anabai gas field is situated in the Moiynkum district of the Zhambyl region in the Republic of Kazakhstan, approximately 210 kilometers north of the city of Taraz.

According to the Anabai Deposit Development Project [14], the component composition of natural gas from the Anabai field was investigated under both surface and reservoir (deep) conditions. Under surface conditions, 56 wellhead gas samples were analyzed from Famennian, Lower, Middle, and Upper Visean, as well as Serpukhovian deposits. Several samples exhibiting anomalously low or high methane contents were excluded from the dataset. The methane concentration under surface conditions was found to range from approximately 88% to 91%, depending on the stratigraphic horizon.

The reservoir gas composition was evaluated based on 102 deep gas samples collected from Famennian, Tournaisian, Lower, Middle, and Upper Visean, and Serpukhovian formations. After excluding anomalous samples, the methane content in the reservoir gas generally ranged from 80% to 83% for Visean and Serpukhovian deposits. In comparison, significantly higher methane concentrations (up to 95-98%) were observed for Tournaisian reservoirs. The Famennian reservoir gas exhibited an average methane content of approximately 90%. Overall, the consistently high methane content across different stratigraphic horizons confirms the suitability of natural gas from the Anabai field as a feedstock for producing synthesis gas.

### 2.2. Catalyst preparation

Overall, the consistently high methane content across different stratigraphic horizons confirms the suitability of natural gas from the Anabai field as a feedstock for producing synthesis gas.

The SHS process is based on the ability of powder mixtures containing fuels and oxidizers to ignite upon local heating, followed by the propagation of a combustion wave throughout the reacting system. This process leads to the formation of solid products with high porosity and developed surface morphology.

For catalyst synthesis, 20 g of precursor materials were used, including 10 g of urea ($CH_4N_2O$) as a fuel, 4 g of cobalt(II) nitrate hexahydrate ($Co(NO_3)_2 \cdot 6H_2O$), 2 g of magnesium nitrate hexahydrate ($Mg(NO_3)_2 \cdot 6H_2O$), and 4 g of aluminum nitrate nonahydrate ($Al(NO_3)_3 \cdot 9H_2O$). The precursors were dissolved in 15 mL of deionized water in a heat-resistant chemical beaker. Urea was employed to ensure stable combustion, with the fuel-to-oxidizer ratio maintained at unity.

The resulting solution was preheated to 80°C under continuous stirring to ensure complete dissolution of the components. The homogeneous solution was then placed into a muffle furnace preheated to 500°C, where combustion occurred over a period of 10-15 minutes. As a result, a solid foam-like material was formed. After synthesis, the obtained material was cooled to room temperature (approximately 20°C) for 30 minutes, crushed into a fine powder, and stored for further use.

### 2.3. Experimental setup and DRM procedure

The DRM experiments were conducted using the laboratory facilities of the JSC Institute of Fuel, Catalysis, and Electrochemistry, named after D.V. Sokolsky. The experimental setup included an automated laboratory unit equipped with a CHROMOS GC-1000 gas chromatograph, a muffle furnace, and analytical laboratory balances.

The reaction was carried out in a quartz tubular reactor, which was installed inside a furnace. The reactor was packed sequentially with glass wool, 2 mL of quartz, 2 mL of the catalyst, followed by another 2 mL of quartz and glass wool to ensure uniform gas flow and temperature distribution. The reactor was positioned such that its central zone coincided with the furnace temperature sensor, allowing accurate control and monitoring of the reaction temperature.

The DRM reaction was conducted at atmospheric pressure using a gas mixture of $CH_4$ and $CO_2$ diluted with argon, with a volumetric ratio of $CH_4$:$CO_2$:Ar = 1:1:1. The total gas flow rate through the reactor was maintained at 100 $mL \cdot min^{-1}$. The dry reforming of methane proceeds according to the following reaction:

$$CH_4 + CO_2 \rightarrow 2H_2 + 2CO, \tag{1}$$

The reactor temperature was increased stepwise from 500°C to 900°C in increments of 100°C. At each temperature, the composition of the reaction products was analyzed every 30 minutes using the CHROMOS GC-1000 gas chromatograph equipped with Chromos software.

## 3. Results and discussion

To assess the reliability of the experimental results, all measurements were performed in duplicate under identical conditions. The reproducibility of the obtained data was satisfactory, indicating a high level of measurement reliability and experimental consistency.

Table 1 summarizes the inlet and outlet concentrations of methane and carbon dioxide obtained during the evaluation of the catalytic activity of the 20Co-10Mg-20Al catalyst in the dry reforming of methane (DRM) reaction over the temperature range of 500-900°C.

At temperatures of 500 and 600°C, the outlet concentrations of methane and carbon dioxide remain close to their inlet values, indicating limited catalytic activity in this temperature range.

***Table 1. Inlet and outlet concentrations of methane and carbon dioxide during DRM over the 20Co-10Mg-20Al catalyst***

| Temperature, °C | $CH_4$ in., % | $CO_2$ in., % | $CH_4$ out., % | $CO_2$ out., % |
|---|---|---|---|---|
| 500 | 33 | 33 | 29.62 | 33 |
| 600 | 33 | 33 | 29.09 | 33 |
| 700 | 33 | 33 | 11.88 | 16.36 |
| 800 | 33 | 33 | 0.33 | 6.29 |
| 900 | 33 | 33 | 0 | 4.91 |

This behavior is typical for DRM, a highly endothermic reaction that requires elevated temperatures to achieve significant reactant conversion.

A pronounced increase in catalytic activity is observed at 700°C, where a substantial decrease in both $CH_4$ and $CO_2$ outlet concentrations is detected. The methane concentration decreases from 33% at the reactor inlet to 11.88% at the outlet, while the $CO_2$ concentration decreases to 16.36%. This temperature marks the onset of effective DRM over the 20Co-10Mg-20Al catalyst.

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The observed temperature-dependent behavior can be attributed to the endothermic nature of the DRM reaction and the increased availability of active sites at higher temperatures. The presence of cobalt as the primary active metal contributes to high methane activation efficiency, while magnesium and aluminum oxides likely enhance catalyst stability and modify surface basicity, facilitating $CO_2$ activation and carbon gasification.

Overall, the results demonstrate that the 20Co-10Mg-20Al catalyst exhibits high catalytic activity in DRM at temperatures above 700°C, with near-complete methane conversion achieved at 800-900°C. These findings confirm the suitability of the investigated catalyst composition for high-temperature DRM applications. They are consistent with trends reported in the literature for Co-based catalysts synthesized via combustion-based methods.

The experimental data obtained in this study are presented graphically in Figures 1-4. The reproducibility of the measurements supports the reliability of the results, as all experiments were performed in duplicate under identical conditions, yielding consistent trends in gas conversion and product composition.

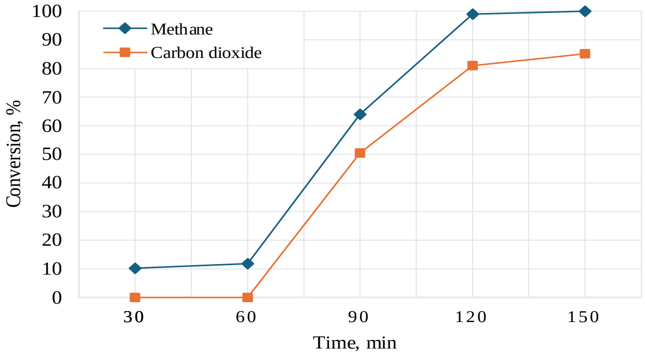


***Figure 1. Dependence of methane and carbon dioxide conversion on reaction time during DRM over the 20Co-10Mg-20Al catalyst***

Figure 1 illustrates the dependence of methane and carbon dioxide conversion on reaction time during DRM over the 20Co-10Mg-20Al catalyst. At short reaction times (30-60 min), the conversion of both reactants remains low, indicating that the catalytic system requires a specific stabilization period under reaction conditions. With increasing reaction time, a pronounced increase in methane conversion is observed, reaching nearly complete conversion after 120-150 min. A similar trend is evident for carbon dioxide, although its conversion remains slightly lower than that of methane throughout the experiment. This behavior suggests progressive activation of the catalyst surface and the establishment of steady-state reaction conditions.

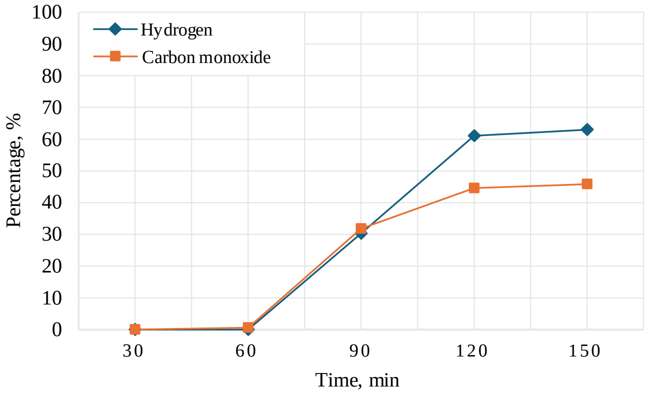


***Figure 2. Dependence of hydrogen and carbon monoxide formation on reaction time during DRM over the 20Co-10Mg-20Al catalyst***

A corresponding increase in the formation of reaction products is evident in Figure 2, which illustrates the evolution of hydrogen and carbon monoxide concentrations over time. The gradual rise in $H_2$ and CO content correlates well with the increasing conversions of $CH_4$ and $CO_2$, confirming that the observed reactant consumption is predominantly associated with the DRM reaction. After approximately 120 min, the product composition approaches a quasi-steady state, indicating stable catalyst performance under the investigated conditions.

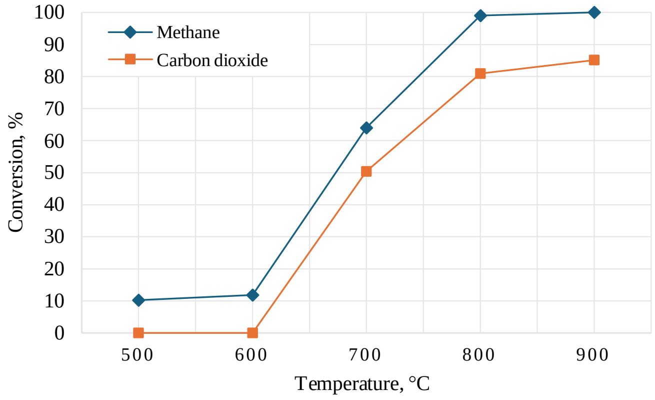


***Figure 3. Effect of reaction temperature on methane and carbon dioxide conversion during DRM over the 20Co-10Mg-20Al catalyst***

The influence of reaction temperature on DRM performance is depicted in Figure 3. Both methane and carbon dioxide conversions exhibit a strong positive dependence on temperature. At 500-600°C, the conversions remain relatively low, reflecting the endothermic nature of DRM and the limited activation of reactant molecules at lower temperatures. A sharp increase in conversion is observed at 700°C, marking the onset of effective DRM over the 20Co-10Mg-20Al catalyst. At 800-900°C, methane conversion reaches nearly 100%, while carbon dioxide conversion exceeds 80%, demonstrating high catalytic activity at elevated temperatures.

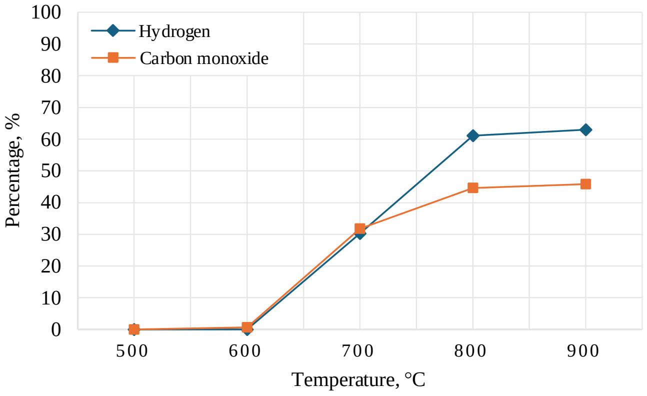


***Figure 4. Effect of reaction temperature on hydrogen and carbon monoxide formation during DRM over the 20Co-10Mg-20Al catalyst***

Figure 4 shows the corresponding effect of temperature on the composition of the gaseous products. The concentrations of hydrogen and carbon monoxide increase significantly with increasing temperature, which is consistent with the enhanced DRM reaction rate. At temperatures above 700°C, the $H_2$ and CO contents rise markedly, approaching values characteristic of synthesis gas suitable for downstream applications. The higher hydrogen yield compared to carbon monoxide can be attributed to the combined contribution of DRM and possible side reactions, such as methane cracking and the reverse water-gas shift reaction.

The catalytic performance of the 20Co-10Mg-20Al system is strongly dependent on both reaction time and temperature. Efficient methane and carbon dioxide conversion, accompanied by high synthesis gas yields, is achieved at temperatures above 700°C and after sufficient reaction time to reach steady-state conditions. These findings confirm the suitability of the investigated catalyst composition for high-temperature DRM. They are in good agreement with general trends reported for Co-based catalysts prepared by combustion-based synthesis methods.

This paper presents a comparative assessment of the behavior of the 20Co-10Mg-20Al catalyst in the DRM reaction at five temperatures: 500°C, 600°C, 700°C, 800°C, and 900°C. The analysis focuses on the calculated conversions of $CH_4$ and $CO_2$, as well as on the composition of the gaseous products, namely CO and $H_2$.

The outlet concentrations of $CH_4$, $CO_2$, CO, and $H_2$ were experimentally measured, and the corresponding conversion values were calculated using the following relationships:

$$X_{\mathrm{CH_4}} = \frac{\mathrm{CH}_4^{in} - \mathrm{CH}_4^{out}}{\mathrm{CH}_4^{in}} \cdot 100\,, \tag{2}$$

$$X_{\mathrm{CO_2}} = \frac{\mathrm{CO}_2^{in} - \mathrm{CO}_2^{out}}{\mathrm{CO}_4^{in}} \cdot 100 \tag{3}$$

The 20Co-10Mg-20Al catalytic system exhibits low activity at the lower temperatures of 500°C and 600°C. Under these conditions, methane conversions reach only 10.2% and 11.8%, respectively, while the formation of syngas components (CO and $H_2$) is negligible. At such temperatures, methane molecules, characterized by strong C–H bonds with a bond dissociation energy of approximately 435 $kJ \cdot mol^{-1}$, cannot be efficiently activated on the surface of the cobalt-based catalyst. As a result, the DRM pathway ($CH_4 + CO_2 \rightarrow 2CO + 2H_2$) is kinetically suppressed.

In contrast, $CO_2$, although thermodynamically stable, can participate in secondary reactions when trace amounts of oxygen or water are present in the system. One possible route for $CO_2$ formation involves the partial oxidation of methane ($CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$), notably if the catalyst has not been fully reduced or if residual oxidized species remain on the support surface. Another pathway is associated with the oxidation of carbon deposits formed during the cracking of methane ($CH_4 \rightarrow C + 2H_2$). These deposits can subsequently react with $CO_2$ via the Boudouard reaction or gasification, leading to additional formation of CO and $CO_2$:

$$C + CO_2 \rightarrow 2CO \tag{4}$$

In both cases, the net effect is an increased concentration of $CO_2$ at the reactor outlet, even though no excess $CO_2$ is introduced into the feed. Such parasitic reactions reduce the overall carbon efficiency of the process, indicating insufficient catalyst activation or limited dispersion of metallic cobalt species at low temperatures.

A significant enhancement in catalytic performance is observed as the temperature increases to 700°C. Under these conditions, methane conversion rises sharply to 64%, while $CO_2$ conversion reaches 50.4%. This increase is accompanied by substantial production of $H_2$ (30.28 mmol) and CO (31.79 mmol), indicating effective activation of the DRM reaction pathway. The pronounced jump in activity is consistent with the known kinetic barriers associated with $CH_4$ dissociation. It suggests that the threshold temperature for efficient C–H bond cleavage on metallic $Co^0$ active sites has been reached. In this context, cobalt plays a crucial role by enabling the dissociative adsorption of methane, resulting in surface-bound carbon ($C^*$) and hydrogen ($H^*$) species, which subsequently react with adsorbed $CO_2$-derived intermediates.

The high methane conversions of 99% and 100%, together with carbon dioxide conversions of 80.9% and 85.1% at elevated temperatures of 800°C and 900°C, respectively, further demonstrate the strong temperature dependence of DRM performance over the investigated catalyst. Such temperatures correspond to conditions close to the thermodynamic equilibrium region for highly endothermic reactions such as DRM. The increased yields of CO and $H_2$ observed at these temperatures indicate enhanced reaction kinetics, higher surface mobility of the reactants, and an increased availability of active metallic $Co^0$ surface sites.

In addition to the intrinsic catalytic activity of cobalt, the role of Mg and Al as support components should also be emphasized. Magnesium oxide introduces basic surface sites that promote the adsorption and activation of $CO_2$. This basicity compensates for the acidic character of $Al_2O_3$, resulting in a balanced support environment that can stabilize CO2 in the form of carbonate or bicarbonate intermediates before their decomposition into reactive $CO_2$ species. Such dual functionality enhances $CO_2$ uptake and contributes to the suppression of carbon deposition by facilitating gas-solid interactions. Moreover, MgO may promote a more uniform dispersion of cobalt species within the support matrix, thereby minimizing sintering at elevated temperatures and improving catalyst durability.

The consistency in the formation of both $H_2$ and CO further suggests that the reverse water-gas shift reaction (RWGS) does not play a dominant role under the investigated conditions. In systems where RWGS becomes significant ($CO_2 + H_2 \rightarrow CO + H_2O$), the $H_2$/CO ratio typically decreases below unity. In contrast, the present results indicate an $H_2$/CO ratio close to unity across the entire temperature range, implying that the DRM pathway proceeds selectively with limited interference from side reactions.

The DRM mechanism over Co-based catalysts is commonly described using a bifunctional model. Methane activation predominantly occurs on metallic cobalt sites, which provide the necessary electronic structure and geometry for the cleavage of C-H bonds. In contrast, $CO_2$ preferentially interacts with oxide supports or oxygen-containing surface species. The coexistence of MgO and $Al_2O_3$ in the catalyst creates a heterogeneous surface with multiple types of active sites. Surface carbon species ($C^*$) formed during methane cracking can readily react with oxygen-containing intermediates derived from adsorbed $CO_2$ (such as $O^*$ or $CO_3^{2-}$), leading to CO formation and completion of the catalytic cycle.

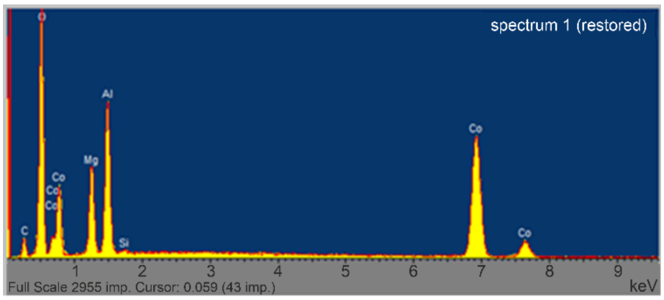
From a performance perspective, the 20Co-10Mg-20Al catalyst exhibits promising characteristics. The sharp increase in conversion between 600°C and 700°C indicates effective thermal activation, while the near-complete methane conversion at 800-900°C reflects high intrinsic catalytic activity. The high yields of $H_2$ and CO, together with a stable $H_2$/CO ratio, further confirm both the efficiency and selectivity of the catalyst under high-temperature DRM conditions.

Nevertheless, certain limitations should be noted. The absence of significant activity at temperatures around 650°C may restrict the applicability of the catalyst in processes designed to operate under milder conditions for improved energy efficiency. Additionally, the present study does not address long-term stability or regeneration behavior, which are crucial parameters for industrial implementation. Coke formation, although not directly reflected in the observed conversion values, remains a persistent challenge in DRM, particularly at elevated temperatures and under conditions where carbon gasification pathways are limited.

In summary, the 20Co-10Mg-20Al catalyst exhibits a distinct activation threshold in the range of 650-700°C, above which it demonstrates high efficiency in the DRM reaction. The synergistic interaction between metallic cobalt, basic MgO, and structurally stable $Al_2O_3$ provides a solid foundation for achieving high $CH_4$ and $CO_2$ conversions, elevated synthesis gas yields, and consistent reaction selectivity.

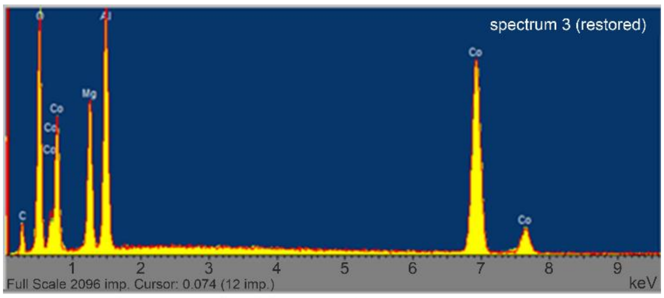
To evaluate the structural and elemental stability of the 20Co-10Mg-20Al catalyst under DRM conditions, a comparative analysis was performed using scanning electron microscopy (SEM) coupled with energy-dispersive X-ray spectroscopy (EDS). Both fresh and spent catalyst samples were examined to assess their morphological features, elemental composition, and surface changes induced by the reaction.

Representative SEM images and corresponding EDS spectra of the fresh and spent catalysts are presented in Figure 5a and Figure 5b, respectively.



Fresh 20Co-10Mg-20Al

(a)



Spent 20Co-10Mg-20Al

(b)

***Figure 5. EDS spectra of the 20Co-10Mg-20Al catalyst: (a) – fresh sample; (b) – spent sample after DRM reaction***

The fresh catalyst sample (Figure 5a) exhibits a porous and well-developed surface morphology, as observed by SEM. Uniformly distributed surface features characterize the structure, with no visible signs of particle agglomeration or sintering. Such morphology is advantageous for DRM, as it provides a high accessible surface area and facilitates the exposure of active catalytic sites. The corresponding EDS analysis confirms the presence of all expected elements, including cobalt (Co), magnesium (Mg), aluminum (Al), and oxygen (O), as well as trace amounts of silicon (Si), which are most likely associated with the substrate or external contamination. The average elemental composition (wt.%) of the fresh catalyst was determined as follows: Co – 47.31%, O – 29.35%, Al – 13.83%, Mg – 9.44%, and Si – 0.07%. These results confirm the successful incorporation of all catalyst components in the intended proportions. The high cobalt content reflects its role as the primary active phase, while MgO and $Al_2O_3$ act as structural and textural stabilizers.

The spent catalyst sample (Figure 5b) also demonstrates favorable structural characteristics after DRM operation. SEM analysis reveals that the overall porous morphology is largely preserved, with no evidence of severe support degradation or cobalt sintering. Although slight surface smoothing and limited particle growth are observed, these changes remain within acceptable limits and do not indicate significant structural deterioration. Filamentous carbon species, typically associated with DRM, are detected on the catalyst surface, confirming catalytic activity during operation. Importantly, no encapsulation of the active phase or extensive aggregation is observed, suggesting that the active cobalt sites remain accessible after reaction.

EDS analysis of the spent catalyst confirms the presence of all key elements across different surface regions. The average elemental composition (wt.%) was determined as: Co – 48.48%, O – 23.29%, Al – 16.57%, and Mg – 11.66%. Compared to the fresh catalyst, the cobalt content increased by approximately 1.17%, which can be attributed to surface enrichment resulting from the reduction of cobalt oxide species to metallic cobalt during the DRM process. Simultaneously, the oxygen content decreased by about 6.06%, consistent with partial lattice oxygen removal under high-temperature and reducing reaction conditions. The relative increase in Al and Mg contents is primarily associated with the decrease in oxygen concentration, which enhances the relative contribution of metallic elements in the EDS signal.

The EDS spectra of the spent catalyst show well-defined cobalt peaks, particularly at approximately 6.9 and 7.6 keV, corresponding to Co Kα and Kβ lines, respectively. This observation confirms the presence and stability of metallic $Co^0$ as the active phase after reaction. The preservation of peak intensity and sharpness indicates the absence of significant cobalt sintering or particle migration during the DRM process. Magnesium and aluminum signals remain stable, confirming the chemical robustness of the MgO-$Al_2O_3$ support matrix under reaction conditions. Trace silicon detected in isolated spectra is considered extrinsic and not intrinsic to the catalyst formulation.

Overall, the SEM-EDS results demonstrate that the 20Co-10Mg-20Al catalyst maintains both structural integrity and elemental stability during DRM operation. The preservation of a porous morphology, stable dispersion of metallic cobalt, and the supportive role of MgO and $Al_2O_3$ collectively contribute to sustained catalytic activity and resistance to severe deactivation mechanisms.

## 4. Conclusions

During the experiments, it was found that the conversion of methane into synthesis gas via DRM using the 20Co-10Mg-20Al catalyst begins at a reaction temperature of 700°C. At a reaction temperature of 800°C, the conversion is nearly complete. Specifically, at a reaction temperature of 600°C, the methane conversion rate is only 11.85%, showing minimal changes. However, at 700°C, the conversion rate increases sharply to 64%, and at 800°C, it reaches 99%. Thus, it can be concluded that for this catalyst and under the given conditions, the optimal temperature for the DRM reaction lies within the range of 700°C to 800°C.

The synthesized gas produced in this reaction has promising potential as a renewable energy source, especially for fuel energy. Considering the high methane content in the Anabai gas field, this technology offers a valuable method for converting methane into hydrogen. Therefore, it is recommended to implement this process at the Anabai gas field, given its promising energy generation capabilities.

The forecasts for implementing this technology are optimistic. In the future, it may lead to a more environmentally friendly energy production process, contributing to the Republic of Kazakhstan's achievement of sustainable development goals, particularly in the energy sector.

This paper demonstrates the prospects of converting natural gas produced at the Anabai gas field into hydrogen, a cleaner fuel. While the technology is still in the early stages and requires further comprehensive scientific research, it holds significant potential. Future studies should focus on discovering new, more effective catalysts for the DRM process. Despite the challenges, this area of research shows great promise and offers opportunities for further advancements in sustainable energy production.

## Author contributions

Conceptualization: BBZ; Data curation: BBZ, BBB; Formal analysis: BBZ, BBB; Funding acquisition: BBZ; Investigation: BBZ, BBB; Methodology: BBZ, BBB; Project administration: BBZ; Resources: BBZ, BBB; Software: BBZ, BBB; Supervision: BBZ, BBB, Zh.S.T; Validation: BBZ, BBB; Visualization: BBZ, BBB; Writing – original draft: BBZ, BBB; Writing – review & editing: BBZ, BBB. All authors have read and agreed to the published version of the manuscript.

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## Conflicts of interests

The authors declare no conflict of interest.

## Data availability statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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# Анабай газ кен орнының өндірілген табиғи газды метанды құрғақ риформинг реакциясы арқылы синтездік газға айналдыру үшін пайдаланудағы перспективалары

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**Аңдатпа.** Құрғақ метан риформингі (ҚМР) синтез газын өндірудің перспективалы тәсілі болып табылады. Белгілі болғандай, синтез газы биоотынның газ тәрізді түрі болып табылады және көміртегі тотығы мен сутегінің қоспасы болып табылады. Сутегі болашақта таза отын ретінде қолданылуы мүмкін. Бұл ғылыми-зерттеу жұмысының мақсаты Анабай газ кен орнының өндірілген табиғи газды ҚМР реакциясы арқылы синтездік газға айналдыру үшін пайдалану перспективаларын көрсету, сонымен қатар ҚМР бойынша зертханалық ғылыми тәжірибелер мысалында метаннан синтез газын алудың тәжірибелік мүмкіндіктерін зерттеу және көрсету болды. Метанды пайдалану және конверсиялау әлеуетін зерделеу үшін жер бетіндегі де, жер қойнауындағы да Анабай кен орнында өндірілген газдың метан құрамдас бөлігі туралы деректер пайдаланылды. Жер үсті газының сипаттамалары Фамен, Төменгі Визей, Орта Визей, Жоғарғы Визей және Серпухов кен орындарынан жиналған 56 ұңғыма сағасының сынамасы арқылы талданды. Жер қойнауының сынамалары Фамен, Турней, Төменгі, Орта және Жоғарғы Визей және Серпухов кезеңіндегі газдардың 102 үлгісінен алынды. Бұл деректер Анабай кен орнындағы метанның орташа мөлшері айтарлықтай жоғары екенін көрсетеді. Бұл мақалада 20Co-10Mg-20Al негізіндегі катализаторды пайдаланып эксперименттер кезінде алынған нәтижелер берілген. Бұл катализатор өздігінен таралатын жоғары температуралық синтез (ӨТЖТС) әдісі арқылы алынды. Алынған нәтижелердің практикалық маңыздылығын ескере отырып, іске асыру бойынша ұсынымдар беріліп, осы Анабай газ кен орнындағы метанның осындай түрленуінің болжамдары мен перспективалары да жасалды.

***Негізгі сөздер:*** *газ кен орны, құрғақ метан риформингі, синтез газы, метан, сутегі.*

# Перспективы использования природного газа газового месторождения Анабай для получения синтез-газа методом сухого риформинга метана

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**Аннотация.** Реакция сухого риформинга метана (СРМ) является перспективным подходом к получению синтез-газа – смеси водорода и оксида углерода, которая может использоваться в энергетических и химико-технологических процессах. В условиях глобального энергетического перехода водород рассматривается как потенциальный низкоуглеродный энергоноситель, при этом СРМ позволяет одновременно утилизировать метан и диоксид углерода. Целью данной работы является оценка перспектив газового месторождения Анабай для преобразования добываемого природного газа в синтез-газ с использованием реакции сухого риформинга метана, а также демонстрация практической реализуемости данного процесса на основе лабораторных экспериментов. Для оценки потенциала использования метана были проанализированы данные по его компонентному содержанию в природном газе месторождения Анабай в поверхностных и глубинных условиях. Характеристика газа в поверхностных условиях выполнена на основе 56 устьевых проб, отобранных из фаменских, нижневизейских, средневизейских, верхневизейских и серпуховских отложений. Глубинные пробы представлены 102 образцами газа из фаменского, турнейского и визейско-серпуховского ярусов. Полученные данные свидетельствуют о стабильно высоком содержании метана во всех исследованных стратиграфических горизонтах. Экспериментальные исследования СРМ были проведены с использованием катализатора состава 20Co-10Mg-20Al, синтезированного методом самораспространяющегося высокотемпературного синтеза (СВС). Каталитическая активность оценивалась по степени превращения метана и диоксида углерода, составу синтез-газа и температурной зависимости процесса. Предложены рекомендации по внедрению технологии сухого риформинга метана на газовом месторождении Анабай, а также рассмотрены перспективы интеграции данного подхода в экологически ориентированные энергетические схемы.

***Ключевые слова:*** *газовое месторождение, сухой риформинг метана, синтез-газ, природный газ, метан, водород.*

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