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STRUCTURAL AND CATALYTIC PROPERTIES OF SCS-DERIVED Co–Al–Mg–Mn CATALYSTS IN DRY REFORMING OF METHANE

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Abstract. The production of valuable synthesis gas through the dry reforming of methane is an important direction in modern catalytic technologies, as this process enables the efficient utilization of greenhouse gases such as CH_4 and CO_2. In this study, Co-Al-Mg-Mn-based catalysts were prepared by solution combustion synthesis (SCS) using metal nitrates as initial components and urea as a fuel. This method is suitable for the rapid formation of porous, multicomponent, catalytically active oxide materials. The phase composition, textural properties, and morphology of the prepared samples were investigated by XRD, BET, SEM, and EDS techniques. XRD analysis revealed the formation of $CoAl_2O_4$, $MgAl_2O_4$, Co_3O_4, CoO, and mixed metal oxide phases, confirming the development of a complex oxide structure. This phase composition may help stabilize active metal centers and preserve the catalyst structure during the reaction. BET results showed that the specific surface area, pore volume, and pore diameter depend on the catalyst composition. These parameters were considered key factors affecting reactant accessibility to active sites and overall catalytic efficiency. SEM-EDS analysis confirmed a porous aggregated morphology and the presence of Co, Al, Mg, Mn, and O elements in the catalyst composition. Among the studied samples, the 20Co-20Al-5Mg-5Mn/50 urea catalyst showed the highest activity in methane dry reforming. Under optimal conditions, CH_4 and CO_2 conversions reached about 98.8%, while H_2 and CO selectivities were 100.0% and 99.5%, respectively. The results indicate that Co-Al-Mg-Mn-based catalysts are promising materials for synthesis gas production, and that SCS is an effective approach for preparing porous and catalytically active multicomponent catalysts.

Keywords: Co-Al-Mg-Mn catalyst, solution combustion synthesis, urea, BET, dry reforming of methane, syngas

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SCS ӘДІСІМЕН ДАЙЫНДАЛҒАН Co–Al–Mg–Mn КАТАЛИЗАТОРЛАРЫНЫҢ МЕТАННЫҢ ҚҰРҒАҚ РЕФОРМИНГІНДЕГІ ҚҰРЫЛЫМДЫҚ ЖӘНЕ КАТАЛИТИКАЛЫҚ ҚАСИЕТТЕРІ

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Аннотация. Метанның көмірқышқылды конверсиясы арқылы құнды синтез-газ алу қазіргі каталитикалық технологиялардың маңызды бағыттарының бірі болып табылады, себебі бұл үдеріс CH_4 және CO_2 сияқты парниктік газдарды тиімді пайдалануға мүмкіндік береді. Осы зерттеу жұмысында Co-Al-Mg-Mn негізіндегі катализаторлар металл нитраттарын бастапқы компоненттер, ал карбамидті отын ретінде қолдана отырып, ерітіндіде жану синтезі (SCS) әдісімен алынды. Аталған әдіс қысқа уақытта кеуекті, көпкомпонентті және каталитикалық белсенді оксидтік материалдар түзуге қолайлы. Дайындалған үлгілердің фазалық құрамы, текстуралық қасиеттері және морфологиясы XRD, BET, SEM және EDS әдістерімен зерттелді. XRD талдауы $CoAl_2O_4$, $MgAl_2O_4$, Co_3O_4, CoO және аралас металл оксидтік фазалардың түзілгенін көрсетті, бұл күрделі оксидтік құрылымның қалыптасуын дәлелдейді. Мұндай фазалық құрам белсенді металл орталықтарының тұрақтануына және реакция барысында катализатор құрылымының сақталуына ықпал етуі мүмкін. BET нәтижелері меншікті беттік аудан, кеуек көлемі және кеуек диаметрі катализатор құрамына тәуелді екенін анықтады. Бұл параметрлер реагенттердің белсенді орталықтарға қолжетімділігіне және жалпы каталитикалық тиімділікке әсер ететін негізгі факторлар ретінде қарастырылды. SEM-EDS талдауы кеуекті агрегатталған морфологияны және Co, Al, Mg, Mn, және O элементтерінің болуын растады. Зерттелген үлгілердің ішінде 20Co-20Al-5Mg-5Mn/50 карбамид катализаторы ең жоғары белсенділік көрсетті. Оңтайлы жағдайда CH_4 және CO_2 конверсиялары шамамен 98,8%-ға жетіп, H_2 және CO селективтіліктері тиісінше 100,0% және 99,5% болды. Нәтижелер бұл катализаторлардың синтез-газ өндіру үшін перспективалы екенін көрсетті. SCS әдісінің практикалық артықшылығы да айқындалды.

Түйін сөздер: Co-Al-Mg-Mn катализаторы, ерітіндіде жану әдісі, карбамид, БЭТ, метанның көмірқышқылды конверсиясы, синтез-газ

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СТРУКТУРНЫЕ И КАТАЛИТИЧЕСКИЕ СВОЙСТВА Co–Al–Mg–Mn КАТАЛИЗАТОРОВ, ПРИГОТОВЛЕННЫХ МЕТОДОМ SCS, ДЛЯ СУХОГО РИФОРМИНГА МЕТАНА

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Аннотация. Получение синтез-газа посредством углекислотной конверсии метана является одним из перспективных направлений современной каталитической химии, поскольку данный процесс позволяет эффективно утилизировать парниковые газы CH_4 и CO_2. В настоящей работе Co–Al–Mg–Mn-катализаторы были синтезированы методом растворного горения (Solution Combustion Synthesis, SCS) с использованием нитратов металлов в качестве прекурсоров и карбамида в качестве топлива. Данный метод обеспечивает быстрое получение пористых многокомпонентных оксидных материалов с высокой каталитической активностью. Фазовый состав, текстурные характеристики и морфология синтезированных образцов исследованы методами рентгенофазового анализа (XRD), низкотемпературной адсорбции азота (BET), сканирующей электронной микроскопии (SEM) и энергодисперсионного анализа (EDS). Результаты XRD-анализа показали формирование фаз $CoAl_2O_4$, $MgAl_2O_4$, Co_3O_4, CoO, а также смешанных оксидных фаз, что свидетельствует о формировании сложной многофазной структуры. Наличие таких фаз способствует стабилизации активных центров и повышению устойчивости катализаторов в условиях реакции. По данным BET установлено, что удельная поверхность, объём пор и средний диаметр пор существенно зависят от состава катализаторов и оказывают влияние на доступность активных центров и общую каталитическую активность. SEM-EDS-анализ подтвердил формирование пористой агрегированной морфологии и наличие в составе образцов элементов Co, Al, Mg, Mn и O. Среди исследованных образцов наибольшую активность в реакции сухого риформинга метана продемонстрировал катализатор 20Co–20Al–5Mg–5Mn/50 карбамид. В оптимальных условиях конверсии CH_4 и CO_2 достигали 98,8 %, а селективность по H_2 и CO составила 100,0 % и 99,5 % соответственно. Полученные результаты свидетельствуют о высокой перспективности Co–Al–Mg–Mn-катализаторов для получения синтез-газа, а также подтверждают эффективность метода SCS для синтеза пористых многокомпонентных каталитических материалов.

Ключевые слова: Co-Al-Mg-Mn катализатор, метод сжигания раствора, карбамид, BET, углекислотная конверсия метана, синтез-газ

Introduction. Methane carbon dioxide conversion, i.e., dry reforming of methane (DRM), is considered one of the important directions in modern catalytic chemistry and low-carbon energy (Agún et al., 2025). This process enables the simultaneous conversion of methane and carbon dioxide into syngas, that is, a mixture of H_2 and CO (Zhu et al., 2024). The environmental significance of the DRM reaction is associated with its ability to convert two major greenhouse gases - CH_4 and CO_2 - into chemically valuable products. Syngas is an important intermediate feedstock for the production of methanol, dimethyl ether, oxo alcohols, and liquid hydrocarbons through Fischer-Tropsch synthesis (Sun et al., 2024). Therefore, DRM technology is regarded as a promising approach in terms of CO_2 utilization, deep processing of natural gas, and efficient management of the carbon cycle.

The general equation of the DRM reaction is as follows:

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

is written in this form, and the standard enthalpy of this reaction is approximately +247 kJ/mol (Agún et al., 2025; Escalante et al., 2024). The strongly endothermic nature of the reaction requires high temperatures; therefore, DRM is commonly carried out in the range of 700-900 °C (Manabayeva et al., 2023). High temperature is necessary to break the strong C-H bonds in the CH_4 molecule; however, these conditions may also enhance catalyst agglomeration and coke formation. For this reason, an efficient catalyst for DRM should not only exhibit high activity but also possess thermal stability and resistance to carbon deposition. Recent literature identifies high energy consumption, catalyst deactivation, and insufficient long-term stability as the main factors limiting the industrial implementation of DRM (Awad et al., 2024). In the DRM reaction, the theoretical H_2/CO ratio is approximately equal to 1, which is suitable for the production of some oxygenated organic compounds and Fischer-Tropsch products. However, under real experimental conditions, the H_2/CO ratio may deviate from 1 due to side reactions. Thermal decomposition of methane can increase the amount of H_2 and lead to carbon formation on the catalyst surface. For example, the Boudouard reaction can convert part of CO into CO_2 and solid carbon, thereby changing the composition of syngas (Colombo et al., 2024). Therefore, when evaluating DRM performance, CH_4 and CO_2 conversions should be considered together with the H_2/CO ratio, carbon formation, and catalyst stability.

Among DRM catalysts, Ni-based systems have been the most extensively studied because Ni exhibits high activity in methane activation and is less expensive than noble metals (Zhu et al., 2024). However, Ni catalysts are prone to sintering and carbon deposition at high temperatures. To overcome these drawbacks, strategies such as confining Ni particles within supports, introducing promoters, developing bimetallic systems, and using oxides with high oxygen mobility have been widely explored in recent years (Shi et al., 2024). Co-based catalysts are considered as an alternative or complementary active component to Ni-based systems for DRM. Metallic Co sites are capable of activating the C-H bonds of CH_4 molecules and, when combined with a properly selected support, can demonstrate high DRM activity. Nevertheless, Co catalysts are also susceptible to agglomeration and coke formation at elevated temperatures (Escalante et al., 2024). Therefore, oxides such as Al_2O_3, $MgAl_2O_4$, CeO_2, La_2O_3, and others are often used as supports or promoters in Co-based catalysts (Sun et al., 2024; Yang et al., 2023).

Al_2O_3 is a widely used support in DRM catalysts because it can provide a high specific surface area and thermal stability. However, the acidic sites on the Al_2O_3 surface may, in some cases, enhance carbon formation(Li et al., 2024). Therefore, the modification of Al_2O_3-based systems with promoters such as Mg, La, Ce, Zr, or Mn is important for improving catalyst stability (Tungatarova et al., 2025). Mg-containing components are used in DRM catalysts as promoters that enhance basic properties. Since CO_2 is an acidic molecule, basic sites such as MgO or $MgAl_2O_4$ can improve CO_2 adsorption and activation. Enhanced CO_2 activation may promote the oxidation of carbonaceous intermediates formed on the catalyst surface and thereby reduce coke formation (Song et al., 2024; Xu et al., 2024). $MgAl_2O_4$ spinel is considered a thermally stable support at high temperatures and may help limit the agglomeration of Ni or Co particles (Zafarnak et al., 2025). Mn is being investigated as a promoter in DRM systems that can improve redox properties and enhance resistance to carbon deposition. The incorporation of Mn may increase the mobility of oxygen species on the catalyst surface and promote the oxidation of carbonaceous intermediates. Studies on Mn-modified Ni-Al catalysts indicate that the main role of the Mn promoter is to improve coke resistance and long-term stability (Manabayeva et al., 2024).

Solution combustion synthesis (SCS) is considered one of the suitable methods for preparing multicomponent catalysts and oxide systems, because this approach is based on a rapid self-sustaining redox reaction between an oxidizer and a fuel in the presence of metal cations. In this process, metal nitrates are commonly used as oxidizers, while organic compounds such as urea, glycine, or citric acid are used as fuels (Deganello et al., 2018; Gao et al., 2017). During the combustion process, high temperatures are generated within a short time, which can lead to the formation of metal oxides, spinels, or solid solutions. The solution combustion method enables the uniform distribution of active components and enhances metal-support interactions. In Co-Al catalysts, the formation of the $CoAl_2O_4$ spinel phase is frequently observed. Although the $CoAl_2O_4$ phase is difficult to fully reduce, it can provide structural stability at high temperatures and limit the growth of Co particles (Tungatarova et al., 2025). In Ni-Co bimetallic systems, the electronic and structural synergy between the metals can facilitate CH_4 activation and improve catalyst stability by suppressing carbon formation (Liu et al., 2023).

The morphology of the catalyst support also has a significant effect on DRM activity and stability (Shen et al., 2020). Li et al., (2024) showed that the morphology of Al_2O_3 determines coke resistance in Ni/Al_2O_3 catalysts. This effect is explained by the interaction of surface OH species with CH_x intermediates, which suppresses carbon formation. Therefore, in the design of DRM catalysts, not only the metal composition but also the surface chemistry, morphology of the support, and mobility of oxygen species are important factors.

In general, literature data demonstrate that the most effective catalysts for DRM should be multifunctional, with stability considered a key criterion alongside catalytic activity. In such catalysts, one type of active site activates the CH_4 molecule, another enhances CO_2 adsorption, while a third function promotes the removal of carbonaceous intermediates (Wang et al., 2024). Analysis of the literature shows that DRM technology has significant scientific potential; however, for industrial application, the long-term stability of catalysts and their resistance to coke formation remain major challenges. Current studies demonstrate that controlling the synergistic interaction among the active metal, support, and promoter is one of the key scientific directions in the design of DRM catalysts. In particular, Co, Ni, Mg, Mn, and Al-containing catalysts prepared by solution combustion synthesis are being considered as promising systems for high-temperature operation, improved resistance to coke formation, and efficient syngas production. Therefore, research in this direction provides an important scientific basis for bringing the DRM process closer to practical application.

Materials and Methods. The catalysts used in this study were prepared by the solution combustion synthesis (SCS) method. A series of samples with different metal nitrate contents was synthesized. The metal nitrate salts were first ground and mixed in a porcelain dish. Then, 10 ml of distilled water preheated to 80 °C was gradually added, and the mixture was stirred in air for several minutes until complete dissolution. The resulting precursor solution was transferred into a 250 ml heat-resistant glass beaker and placed in a muffle furnace preheated to 500 °C. Thermocouples were used to monitor temperature changes during synthesis. After 2-3 min, the combustion process was visually observed without fully opening the furnace door. During combustion, the mixture foamed and rose along the beaker walls. After completion, the beaker was cooled in air, and the obtained catalyst was stored in sealed glass containers. The initial solution, combustion process, and final catalyst sample are shown in Figure 1.

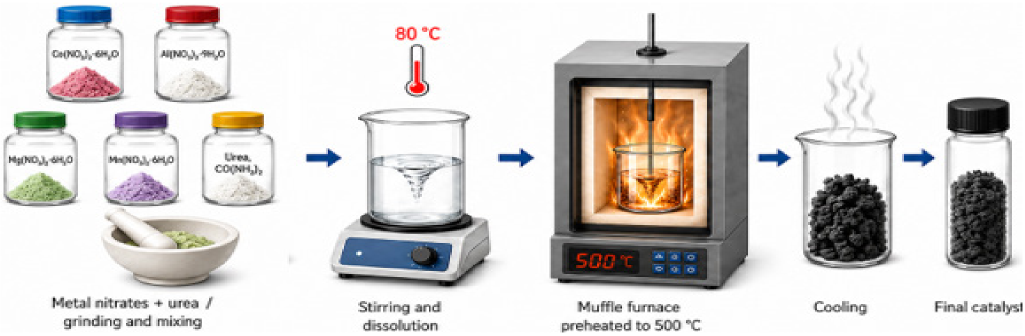

Figure 1. Schematic representation of the catalyst synthesis procedure using the solution combustion synthesis (SCS) method.

The catalytic activity of the catalysts in methane carbon dioxide conversion and oxidation processes was investigated using a laboratory flow-catalytic setup (AKQ-1). The setup consists of a feed gas mixture preparation system, a flow-type quartz tubular reactor, and a chromatographic system for analyzing the reaction products. The catalyst with a volume of 2 ml was placed into a quartz reactor, and the reaction temperature was increased from 600 to 900 °C in 50 °C increments. The feed gases were supplied through pressure regulators, filters, and gas flow controllers to prepare the required reaction gas mixture. A portion of the vapor-gas mixture leaving the reactor was directed to chromatographic analysis. The reaction products were analyzed after 20 min of reaction and subsequently after every 60 min of catalyst operation. The composition of the initial gas mixture and reaction products was determined using CHROMOS GC-1000 and Agilent Technologies 6890N gas chromatographs. H_2, O_2, N_2, CH_4, C_2–C_4 hydrocarbons, CO, and CO_2 were analyzed using packed columns, while liquid organic compounds were analyzed using a capillary column.

The synthesized catalysts were characterized by X-ray phase analysis (XRD) at the Laboratory of Advanced Ceramics, Institute of Nanoscience and Nanotechnology, National Centre for Scientific Research "Demokritos" (Greece). The analysis was carried out using a Siemens Spellman DF3 spectrometer with Cu-Kα radiation (λ = 1.5406 Å) in the 2θ range of 5-100° with a step size of 0.03°. To determine the phase composition of the samples, the obtained diffraction patterns were compared with standard data from the JCPDS (Joint Committee on Powder Diffraction Standards) database.

The morphology and elemental composition of the samples were determined at the Laboratory of Physicochemical Research Methods of the D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry using a JEOL JSM-6610LV scanning electron microscope. This instrument operates at an accelerating voltage of up to 30 kV and provides high-resolution imaging. The SDD Oxford X-Max 50 mm² X-ray detector installed on the microscope enabled elemental analysis of the samples by the EDS method.

The textural properties of the prepared catalysts and supports, including specific surface area, pore volume, and pore size distribution, were determined by the BET (Brunauer-Emmett-Teller) method using a GAPPV–Sorb 2800 instrument. Nitrogen with a purity of 99% and helium with a purity of 99% were used as carrier gases. The pore volume and average pore diameter of the samples were calculated by the BJH method using the desorption branch of the adsorption–desorption isotherms.

The main parameters of the performed process were calculated using the following equations:

$$X_{CH4}\,(\%) = \frac{(F_{CH_4,in} - F_{CH_4,out})}{F_{CH_4,in}} \times 100\% \tag{2}$$

$$X_{CO2}\,(\%) = \frac{(F_{CO_2,in} - F_{CO_2,out})}{F_{CO_2,in}} \times 100\% \tag{3}$$

Results and Discussion. Co-Al-Mg-Mn-based catalysts with different component ratios were prepared by the solution combustion synthesis method, and the catalytic activity of the following samples was investigated: 30Co-5Mg-10Al-5Mn/50 urea, 20Co-5Mg-20Al-5Mn/50 urea, 12,5Co-12,5Mg-12,5Al-12,5Mn/50 urea, 3Co-3Mg-3Al-41Mn/50 urea.

The physicochemical characterization results showed that, among the investigated Co-Al-Mg-Mn catalyst series, the 20Co-20Al-5Mg-5Mn/50 urea sample possessed the most favorable structural and textural properties. According to Table 1, this catalyst was characterized by the highest specific surface area (16.6 m^2 g^{-1}), the largest pore volume (0.063 cm^3 g^{-1}), and the greatest average pore diameter (22.9 nm). After the reaction, only a slight decrease in these parameters was observed, indicating that the porous structure of the catalyst was largely preserved under DRM conditions. Such textural features can facilitate the diffusion of reactants and improve the accessibility of active sites.

Table 1. Textural properties of Co–Al–Mg–Mn catalysts prepared by solution combustion synthesis.

Catalyst	S_{BET} (m^2 g^{-1})	Pore volume (cm^3 g^{-1})	Average pore diameter (nm)
30Co-5Mg-10Al-5Mn/50 urea	14,6	0,054	19,3
20Co-5Mg-20Al-5Mn/50 urea (fresh)	16,6	0,063	22,9
12,5Co-12,5Mg-12,5Al-12,5Mn/50 urea	7,5	0,022	11,8
3Co-3Mg-3Al-41Mn/50 urea	7,4	0,063	10,0
20Co-5Mg-20Al-5Mn/50 urea (spent)	16,0	0,052	21,1

X-ray phase analysis results (Figure 2) showed the formation of mixed oxide and spinel phases in the catalyst, such as $CoAl_2O_4$, cobalt oxides, $MgCo_2O_4$, and $MgAl_2O_4$. The formation of these phases indicates strong interaction between cobalt species and the oxide matrix. Such a mixed oxide structure can contribute to limiting the agglomeration of the active phase at high temperatures and improving the thermal stability of the catalyst.

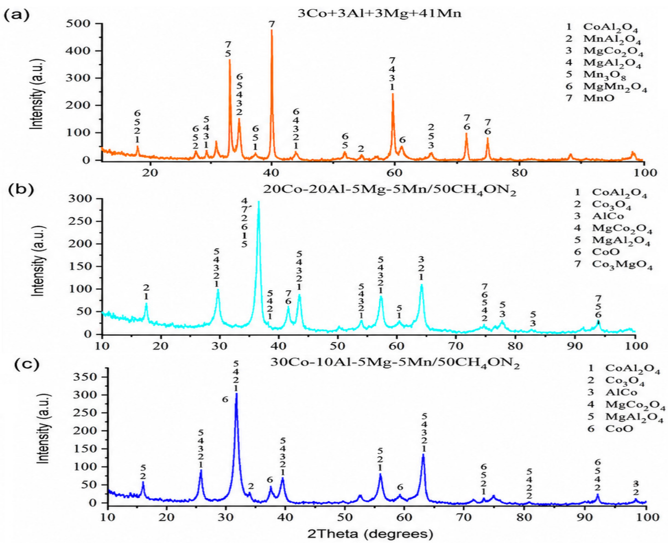

Figure 2. XRD patterns of Co–Al–Mg–Mn-based catalysts with different compositions prepared by the solution combustion synthesis (SCS) method: (a) 3Co-3Al-3Mg-41Mn/50urea, (b) 20Co-20Al-5Mg–5Mn/50urea, and (c) 30Co-10Al-5Mg-5Mn/50urea. The identified crystalline phases are marked by numbered label.

The catalyst morphology was also confirmed by SEM/EDS and TEM results. SEM images of the fresh catalyst (Figure 3a) showed a porous and irregularly aggregated morphology typical of the solution combustion synthesis method, while the EDS spectra confirmed the presence of Co, Al, Mg, Mn, and O elements in the sample. SEM images after the reaction (Figure 3b) indicated that the overall morphology of the catalyst was preserved, suggesting that no significant structural degradation occurred. TEM analysis showed that the catalyst mainly consisted of particles with sizes of approximately 20–30 nm. Such an aggregated nanostructure can ensure sufficient dispersion of the active phase and contribute to the preservation of structural stability under high-temperature conditions.

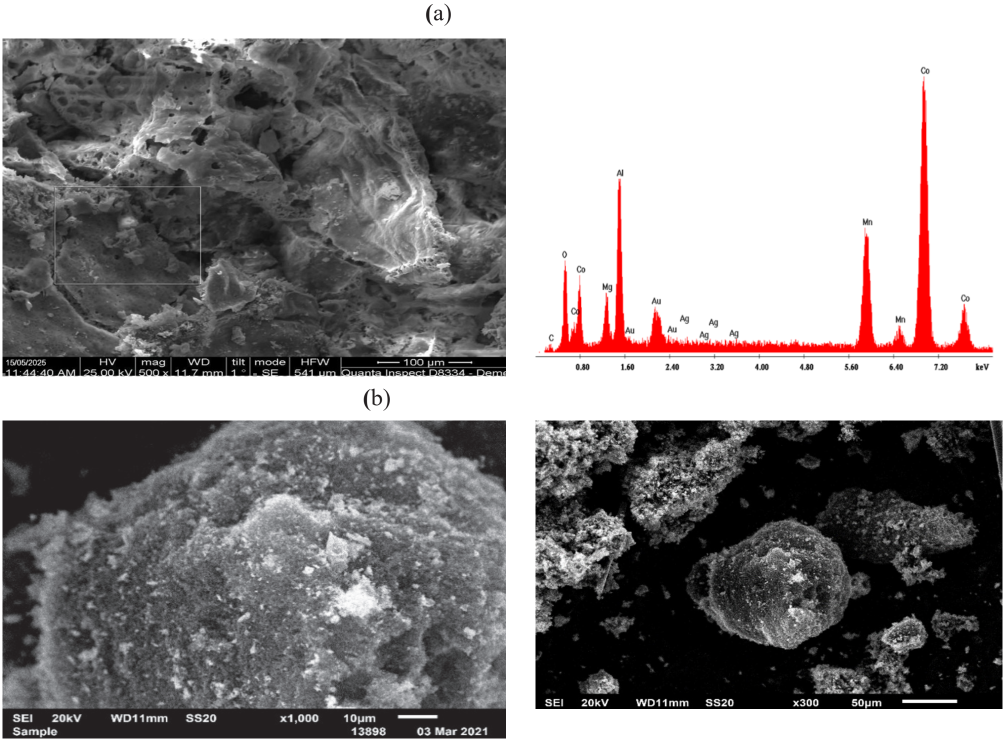

Figure 3. SEM micrographs and EDS spectrum of the Co-Al-Mg-Mn-based catalyst: (a) fresh catalyst and (b) spent catalyst after catalytic reaction, showing changes in surface morphology and elemental composition.

Thus, the physicochemical characterization confirmed that the 20Co-5Mg-20Al-5Mn/50 urea catalyst exhibits several important features for DRM, such as a high specific surface area, developed mesoporosity, stable mixed oxide-spinel phases, and structural morphology retained after the reaction.

The study identified the 20Co-5Mg-20Al-5Mn/50 urea sample as the most effective catalyst for the DRM reaction. Its catalytic properties were investigated at atmospheric pressure using a gas mixture containing 33,3% CH_4, 33,3% CO_2, and 33,3% Ar. As the temperature increased, the conversions of CH_4 and CO_2 also increased, reaching nearly complete values in the high-temperature region (Figure 4a), which is associated with the endothermic nature of the DRM reaction. The increase in H_2 and CO selectivities with temperature (Figure 4b) indicated that syngas formation became predominant at elevated temperatures.

The effect of space velocity is presented in Table 2. Under the investigated conditions, the most favorable overall performance was observed at 1000 h^{-1}. At this space velocity, the CH_4 and CO_2 conversions reached 98,8%, while the H_2 and CO selectivities were 100,0% and 99,5%, respectively. As the space velocity increased, the contact time between the reactants and the catalyst surface decreased, resulting in lower conversion and selectivity. At lower space velocity, although the reactant conversion remained high, no additional advantage in terms of syngas quality was observed. The variation of the H_2/CO ratio in the range of 1,3-1,7 indicates that, along with the main DRM pathway, side reactions promoting hydrogen formation may also occur.

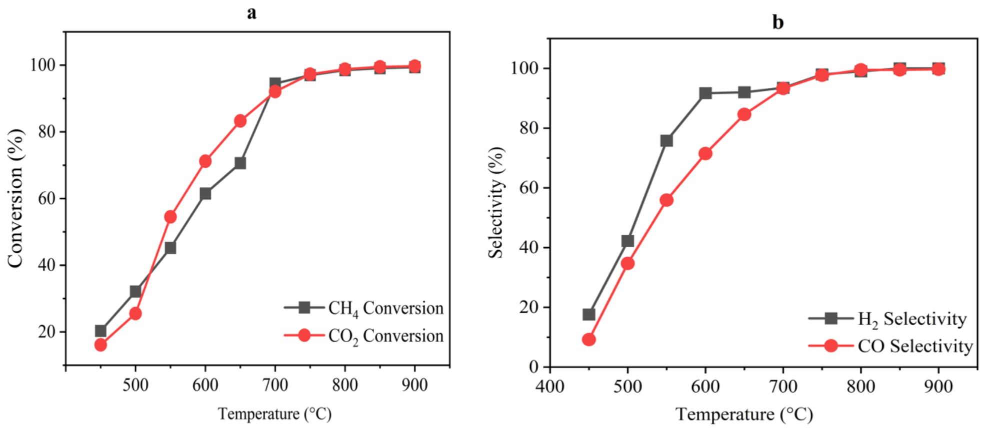

Figure 4. Temperature-dependent catalytic performance of the 20Co-20Al-5Mg-5Mn/50 urea catalyst in methane dry reforming: (a) CH_4 and CO_2 conversions; (b) H_2 and CO selectivities.

Table 2. Effect of gas hourly space velocity on the DRM performance of the 20Co-5Mg-20Al-5Mn/50 urea catalyst.

Space velocity (h^{-1})	CO (%)	H_2 (%)	X_{CH4} (%)	X_{CO2} (%)	S_{H2} (%)	S_{CO} (%)	H_2/CO
500	38,4	58,2	99,1	98,2	83,6	98,5	1,4
1000	39,7	65,5	98,8	98,8	100	99,5	1,7
1500	37,8	52,9	97,7	95,5	81,0	96,4	1,3
2000	37,5	47,7	99,1	95,5	72,6	96,2	1,3
3000	37,0	50,5	99,0	96,1	76,9	96,6	1,4
4000	33,0	51,3	94,9	91,9	79,7	92,5	1,6

In general, the high DRM activity of the 20Co-5Mg-20Al-5Mn/50 urea catalyst is directly related to its favorable textural properties, stable mixed oxide structure, and morphology retained after the reaction. The high specific surface area and relatively large pores improve the accessibility of reactants, while Co-Al-Mg-Mn based mixed oxides ensure the stability of the active phase at high temperatures. The combination of these factors indicates that this sample is the most effective DRM catalyst among the investigated series.

Conclusion. Co-Al-Mg-Mn-based multicomponent catalysts were prepared by the solution combustion synthesis method and investigated in the dry reforming of methane. XRD results showed the formation of $CoAl_2O_4$, $MgAl_2O_4$, $MgCo_2O_4$, Co_3O_4, CoO, and mixed metal oxide phases, while BET, SEM-EDS, and TEM analyses confirmed their porous aggregated morphology, favorable textural properties, and structural stability after the reaction. Among the investigated samples, the 20Co-5Mg-20Al-5Mn/50 urea catalyst exhibited the best performance, with a specific surface area of 16,6 m²/g, a pore volume of 0,063 cm^3/g, and an average pore diameter of 22,9 nm. In catalytic tests, this sample achieved CH_4 and CO_2 conversions of 98,8% and H_2 and CO selectivities of 100,0% and 99,5%, respectively, at a space velocity of 1000 h^{-1}. These results demonstrate that the SCS method is effective for preparing porous and active multicomponent catalysts, and that the 20Co-5Mg-20Al-5Mn/50 urea catalyst is a promising material for syngas production.

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