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ACTIVITY AND SELECTIVITY OF SOME INDIVIDUAL AND BINARY METAL OXIDE MIXTURES IN THE OXIDATION PROCESS OF CARBON MONOXIDE AND NATURAL GAS

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ABSTRACT

This article aims to investigate the activity and selectivity of metal oxides during the oxidation of carbon monoxide and hydrocarbons. According to the experimental results, it was established that the highest reactivity of the studied individual and binary metal oxides during the carbon monoxide oxidation process is characteristic of the mixture of oxides with the composition $0.7CuO + 0.3MnO_2$. The influence of gas medium parameters on the activity of this catalyst was studied, as a result of which optimal conditions for the oxidation process were found. The selected catalyst composition, consisting of copper and manganese oxides, allows for the selective oxidation of carbon monoxide in the presence of hydrocarbons at low temperatures (250 °C). The activity and selectivity of catalysts consisting of individual and binary metal oxides during the oxidation of hydrocarbons (methane, natural gas, gasoline vapors) have been established. As a result, it was proven that the composition of the system with the highest activity for the studied process is $0.8CoO + 0.2Cr_2O_3$. This catalyst, consisting of $0.8CoO + 0.2Cr_2O_3$, exhibits high activity in the oxidation of various combustion exhaust gases at 300 °C. The obtained results provide a basis for developing efficient metal oxide catalysts for exhaust gas purification and emission control. This study supports the United Nations Sustainable Development Goal (SDG 13: Climate Action) by contributing to cleaner catalytic technologies.

Keywords: Catalyst, Carbon Monoxide, Gasoline, Hydrogen, Metal Oxide, Natural Gas, Propane-Butane.
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INTRODUCTION

Carbon monoxide and hydrocarbons (methane, natural gas, gasoline vapors, etc.) are the most toxic and explosive compounds emitted into the atmosphere as part of the exhaust gases of furnaces and internal combustion engines of various designs.[1-3] The ambient atmospheric air of CO and hydrocarbons is mainly emitted from various anthropogenic sources.[4,5] Sources of anthropogenic pollution of the air include all heat engines using hydrocarbon fuel and furnaces of various designs. Gases emitted into the atmosphere from internal combustion engines (automobile, air, sea, river and railway transport) account for an average of more than 50% of harmful gas emissions; furnaces of various designs of energy and industrial facilities emit an average of about 40% of pollutants into the atmosphere, and up to 10% of emissions are emitted from other sources.[6, 7] More than 50% of the exhaust gases emitted into the air from various engines are oxides of carbon, and up to 5-20% are hydrocarbons.[7,8] The rapid development of energy, industry and transport leads to an increase in the demand for hydrocarbon fuels, which in turn further increases the amount of combustion products emitted into the atmosphere. It should be noted that 12-14 kilograms of atmospheric air are required to burn one kilogram of hydrocarbon fuel.[9,10] Carbon monoxide and hydrocarbons emitted into the atmosphere from various sources are among the compounds that have a very serious negative impact on human health, fauna and flora.[11] It is known that one of the main methods for reducing the amount of CO and hydrocarbons emitted into the atmosphere from various sources is their oxidation with the participation of active catalytic systems.[12] The main part of such catalysts is made

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up of metal oxides. In addition, selective and sensitive thermocatalytic and semiconductor chemical sensors and photocatalysts are developed on the basis of catalytic systems consisting of metal oxides.[13] Therefore, studying the laws of the oxidation of carbon monoxide and hydrocarbons with the participation of metal oxides and choosing active and selective catalysts for the processes under investigation is one of the current urgent problems. Investigations on the selection of catalysts for the oxidation of carbon monoxide and hydrocarbons have been carried out actively for decades. As a result of these studies, a number of methods and catalysts have been developed for purifying the composition of exhaust gas mixtures from various toxic and explosive gases, and a catalyst containing aluminium oxide and rare earth element oxides has been proposed.[14] This catalyst has high activity in the oxidation of carbon monoxide and hydrocarbons. Catalytic oxidation of CO is a process widely used in industry. Examples include the production of synthesis gas from methane or liquid hydrocarbons; purification of exhaust gases from internal combustion engines, gasification waste from petrochemical and metallurgical production processes, and others.[15-19] The choice of purification methods is largely determined by the composition of the gas mixture, the amount of CO in it and the problem to be solved.[20-23] Several methods of CO purification are known, such as sorption, high-temperature combustion to carbon dioxide and catalytic oxidation.[24-27] Sorption processes are less promising for cleaning large volumes of gas, and combustion of CO to CO_2 is effective only at high concentrations of CO. Catalytic oxidation of CO is the most reasonable and promising method of gas purification, which allows not only to remove toxic CO, but also to obtain an equivalent amount of hydrogen when converting it with water vapor.[28-30] Copper-containing catalysts for the oxidation of CO with oxygen are of great interest, which, despite their high sensitivity to poisons and low thermal stability, work in processes at temperatures up to 320-350 °C. In all industrialised countries of the world, intensive research is being conducted on the use of catalysts based on platinum, osmium, palladium metals and metal oxides to purify atmospheric air and exhaust gases from toxic and explosive gases (including carbon monoxide and hydrocarbons). However, since most catalysts contain precious metals, the cost of such catalysts remains high. The cost of catalysts based on metal oxides is low, and the number of works in the field of creating active and selective catalysts is limited. The purpose of this paper is to choose active catalysts for the selective oxidation of carbon dioxide and carbon dioxide from the exhaust gases of combustion processes and atmospheric air based on metal oxides.

EXPERIMENTAL

During the study, the oxidation processes of carbon monoxide and hydrocarbons were investigated using a number of divalent metal oxides. The main experiments were carried out in a reactor containing a fixed catalyst film. The required temperature in the reactor was maintained with an accuracy of ±1.0 °C. During the experiments, the corresponding gas–air mixture was supplied from a cylinder to the apparatus. After passing through the catalyst layer in the reactor, a portion of the mixture was periodically directed to the chromatographic column. The oxidation level of the component was determined from chromatographic data recorded before and after passage through the catalyst layer. The amount of mixture components was determined according to a previously established calibration curve. The elemental composition of the prepared catalyst samples was investigated using a Rigaku NEX DE VS EDXRF spectrometer. Prior to the experiments, all samples were pressed into tablets. The structure and phase composition of the catalysts were studied using a Shimadzu Maxima 7000 X-ray diffractometer. Monochromatic Cu Kα radiation (λ = 1.54 Å) was used to obtain diffraction signals. A chromatograph equipped with a flame ionization detector was used to monitor the oxidation processes of hydrocarbons (gasoline vapors). The chromatographic conditions for monitoring oxidation products of gasoline and diesel fuel were as follows: a 1 m long column with an internal diameter of 3 mm, packed with Chromaton coated with 5% Apiezon-L, was used; the column temperature was maintained within the range of 150–200 °C; argon was used as the carrier gas at a flow rate of 50 mL/min.

RESULTS AND DISCUSSION

The oxidation process of combustible compounds depends on factors such as the composition and concentration of the initial components, as well as the reaction temperature. In the conducted studies, the influence of these parameters was investigated. The interaction of carbon monoxide, natural gas, and

gasoline vapors with atmospheric oxygen was studied using catalysts composed of platinum group metals, various oxides, and their mixtures. The reactions of exhaust gas components CO and CH_4 with oxygen have been thoroughly studied using Pt- and Pd-based catalysts. However, semiconductor materials have been less explored in this process. Among metal oxides, the most active catalysts for oxidation processes are Fe_2O_3, MnO_2, TiO_2, ZnO, SnO_2, WO_3, ZrO_2, Cr_2O_3, and CuO. For catalytic oxidation to occur, the presence of vacant sites in the outer sphere of metal cations is essential. This condition is more characteristic of oxygen-containing compounds than of chlorine- or sulfur-containing compounds. Therefore, oxides exhibit significantly higher catalytic activity compared to chlorine- and sulfur-containing compounds. Various metal oxides exhibit considerable catalytic activity toward the oxidation of CO, H_2, and CH_4, and therefore are extensively applied in air purification and gas treatment processes. In oxidation reactions, the stability of metal oxides is generally higher than that of the corresponding metals. Along with activity and stability, selectivity is regarded as one of the fundamental characteristics of a catalyst. It reflects the ability of a catalyst to accelerate only one specific reaction among several simultaneous processes. It should be noted that studies on the oxidation of combustible substances are mainly directed toward the selection of highly active catalysts, whereas questions related to selectivity remain insufficiently addressed. Moreover, due to inconsistencies in available data for catalysts of different compositions, it is often difficult to draw conclusions about selectivity for many processes. The selection and development of catalysts is one of the main challenges in catalysis science. Therefore, this process is primarily carried out experimentally. The catalytically active layer was prepared by impregnating an inert support with a solution of metal salts (nitrates, carbonates, or oxalates). The obtained active layer was dried at temperatures of 100–130 °C and then thermally treated at the decomposition temperature of the salt. Experiments aimed at establishing the optimal conditions for the catalytic oxidation of hydrogen, carbon monoxide, and gasoline vapors were performed at a gas–air mixture flow rate of 5 L/h over a broad range of combustible component concentrations. In the presence of active components in the gas-sensitive layer of the semiconductor sensor, combustion processes predominantly proceed in the thermodynamically most favorable direction, resulting in the formation of CO_2 and H_2O. The search for oxidation catalysts for H_2, CH_4, CO, and hydrocarbons was carried out using the above-mentioned metal oxides. In these experiments, the catalyst layer thickness was 0.5 cm, and the linear velocity of the gas–air mixture was 10 L/min. Samples with a volume of 0.1 mL were taken from the reaction mixture every 10 min. In the gas–air mixture, the partial pressure of combustible components - CO, CH_4, n-octane, and H_2- was P(comp.) = 0.02 atm. For oxygen, the partial pressure was $P(O_2)$ = 0.2 atm, while the total system pressure was P(total) = 1 atm. Changes in the composition of the reaction mixture were monitored by gas chromatography before and after passing through the catalyst layer. The activity and selectivity data obtained for individual metal oxides during the catalytic oxidation of combustible compounds are summarized in Table-1.

Table-1: Selection of Metal Oxides for the Development of Gas-Sensing Elements for Semiconductor Sensors of Combustible Gases (CO, CH_4, H_2, n-octane). (the tested mixture contains: P(CO) = 0.02 atm., $P(CH_4)$ = 0.02 atm., $P(H_2)$ = 0.02 atm., P(n-octane) = 0.02 atm., $P(O_2)$ = 0.02 atm., P(total) = 0.02 atm., temperature of the experiment 350 ºC)

No.	Metal oxide	Degree of oxidation of the component(x±ΔX), %			
		CO	CH_4	n-octane	H_2
1	NiO	29.5±0.4	34.0±0.3	69.5±0.5	53.0±0.3
2	Co_2O_3	55.3±0.6	24.0±0.3	31.5±0.3	82.3±0.6
3	ZnO	43.0±0.3	36.5±0.5	50.0±0.5	67.0±0.7
4	CuO	91.0±1.2	42.0±0.6	76.0±0.8	49.5±0.5
5	Cr_2O_3	70.0±0.8	68.0±1.0	79.0±0.6	76.5±0.9
6	Fe_2O_3	58.0±0.2	31.5±0.3	68.0±0.8	31.5±0.3
7	CoO	47.0±0.3	80.0±0.7	84.0±0.9	79.0±1.3
8	Al_2O_3	2.00±0.1	7.00±0.1	21.0±0.3	6.00±0.1
9	TiO_2	40.5±0.3	40.0±0.3	64.0±0.5	75.3±0.5
10	MnO_2	88.0±0.4	50.0±1.0	74.0±0.5	80.5±0.8
11	ZrO_2	6.00±0.1	2.10±0.1	0.90±0.1	100±1.3

12	SnO_2	86.0±1.1	30.0±0.5	59.5±0.5	84.0±0.7
13	SiO_2	3.00±0.1	2.00±0.1	4.00±0.6	8.00±0.1
14	V_2O_5	46.0±0.5	16.0±0.2	45.5±0.5	41.0±0.4
15	WO_3	37.5±0.5	27.0±0.3	36.0±0.3	50.0±0.4

As can be seen from Table-1, in the system consisting of CO, CH_4, n-octane, and hydrogen, hydrogen is the most readily oxidized component. In most of the oxygen-containing compounds of the studied metals, the oxidation degree of hydrogen reaches 50–100%. ZrO_2 exhibits the highest selectivity toward hydrogen oxidation. In its presence, hydrogen is oxidized completely, whereas the oxidation degrees of CO, CH_4, and n-octane are 6%, 2.1%, and 0.9%, respectively. It can also be seen from Table-1 that at 350 °C carbon monoxide undergoes oxidation to a certain extent over all the studied catalysts. The most suitable metal oxides for this process include CuO, MnO_2, SnO_2, and Cr_2O_3. Under the investigated experimental conditions, the conversion of carbon monoxide to carbon dioxide by atmospheric oxygen ranged from 70% to 91% in the presence of the examined metal oxides. Among them, Fe_2O_3, CoO, Co_2O_3, V_2O_5, ZnO, and TiO_2 exhibited moderate catalytic activity toward CO oxidation. These metal oxides provided carbon monoxide oxidation from 40% to 68%. Among the compounds tested for activity and selectivity WO_3, NiO, ZrO_2, SiO_2, Al_2O_3 showed lower activity. At a temperature of 350 ºC carbon monoxide is practically not oxidized in the presence of SiO_2, Al_2O_3. Experiments performed under the selected conditions (gas–air mixture flow rate 10 mL/min, particle size ~0.1 mm, partial pressures in the gas–air mixture: P(CO) = 0.02 atm, $P(O_2)$ = 0.20 atm, P(total) = 1.0 atm, reaction temperature 350 °C) made it possible to establish the following order of catalytic activity of metal oxides in soot oxidation: CuO (91.0) > MnO_2 (88.0) > SnO_2 (86.0) > Cr_2O_3 (70.0) > Fe_2O_3 (58) > Co_2O_3 (55) > CoO (47) > V_2O_5 (46) > ZnO (43) > TiO_2 (40.5) > WO_3 (37.5) > NiO (29) > ZrO_2 (6) > SiO_2 (3) > Al_2O_3 (2). For n-octane (degree of oxidation %): CoO (84.0) > Cr_2O_3 (79) > CuO (76.0) > MnO_2 (74.0) > NiO (69.5) > Fe_2O_3 (68.0) > TiO_2 (64.0) > SnO_2 (59.5) > ZnO (50.0) > V_2O_5 (45.5) > WO_3 (36) > Co_2O_3 (31.5) > Al_2O_3 (21.0) > SiO_2 (4.0) > ZrO_2 (0.9). The data obtained show that the most active catalysts for the oxidation of hydrocarbon vapours are CoO, Cr_2O_3, CuO and MnO_2. The degree of conversion of n-octane in the presence of these oxides at a temperature of 350 ºC is 70 and 84%, which is slightly higher than the degree of oxidation of methane in the presence of these oxides. Comparison of the results of the oxidation of hydrocarbons (methane and n-octane) in the presence of metal oxides determined in this work (Table-1) with the physical parameters of these metal oxides allows us to propose the following patterns:

1. The high catalytic activity of metal oxides in the oxidation of methane and octane corresponds to oxides with a large bond length between the metal and oxygen atoms in these oxides (Co_2O_3 – 2.63 and Cr_2O_3 -2.01).
2. Metal oxides with relatively small bandgap widths (MnO_2 -0.6; Co_2O_3-0.7; Cr_2O_3-0.9; CuO-1.4) ensure high oxidation of hydrocarbons.

In recent studies, the oxidation process of carbon monoxide and hydrocarbons in the presence of mixed (binary) metal oxides was studied. In many catalytic processes, the catalytic activity and selectivity of individual oxides are lower than those of their complex mixtures. Therefore, subsequent studies on the selection of active and selective components for the oxidation processes of carbon monoxide and hydrocarbons were carried out with the participation of binary mixtures of metal oxides.

The characteristics of the mixture of the most active and selective metal oxides (CoO, Co_2O_3, Cr_2O_3, CuO, MnO_2, NiO, Fe_2O_3, TiO_2, SnO_2, ZnO, etc.) obtained in a 1:1 ratio was studied in experiments.

The activity and selectivity data obtained for several binary oxide systems in the oxidation of selected gases are presented in Table-2.

Table-2: Activity and Selectivity of Binary Metal Oxides During Oxidation of Combustible Gases (CO, CH_4, H_2, n-octane) (in the tested mixture). (the tested mixture contains: P(CO) = 0.02 atm., $P(CH_4)$ = 0.02 atm., $P(H_2)$ = 0.02 atm., P(n-octane) = 0.02 atm., $P(O_2)$ = 0.02 atm., P(total) = 0.02 atm., temperature of the experiment 350 ºC, n=5.P=0.95)

Metal oxides in 1:1 mole ratio	Oxidation degree of the component (x±ΔX). %			
	CO	CH_4	n-octane	H_2
CoO + SnO_2	66.0±0.5	55.3±0.4	71.8±06	88.0±0.7

CoO + ZnO	35.5±0.5	88.0±0.9	87.0±1.2	91.0±0.8
CoO+ CuO	69.9±0.7	71.4±0.9	80.3±0.9	100±1.0
CoO+ NiO	38.5±0.4	57.5±0.5	78.3±1.0	96.0±0.9
CoO+ TiO_2	63.0±0.6	80.3±0.9	84.5±1.1	84.0±0.8
CoO+ Cr_2O_3	98.5±0.7	94.0±1.3	91.5±1.3	100±1.2
CoO+ MnO_2	67.5±0.8	65.0±0.9	79.0±0.7	71.0±0.8
CoO+ Fe_2O_3	22.5±0.4	30.5±0.5	38.8±0.4	95.0±1.1
Cr_2O_3+Fe_2O_3	64.3±0.5	49.5±0.4	55.5±0.8	100±1.3
Cr_2O_3+ NiO	39.5±0.2	45.4±0.5	50.8±0.5	80.0±0.7
Cr_2O_3+ CuO	80.5±0.8	55.0±0.7	77.5±0.9	89.0±0.8
Cr_2O_3+ TiO_2	85.3±1.1	64.3±0.5	71.5±0.6	100±1.1
Cr_2O_3+ SnO_2	78.6±1.0	49.5±0.7	69.3±0.8	100±1.5
Cr_2O_3+ MnO_2	79.1±0.9	59.4±0.6	76.0±0.7	89.0±0.9
Cr_2O_3+ ZnO	56.5±0.6	51.9±0.5	64.5±0.6	100±0.8
CuO+ MnO_2	100±1.5	12.3±0.3	15.7±0.4	100±1.0
CuO+ NiO	50.4±0.5	38.1±0.4	44.3±0.5	89.0±1.0
CuO+ SnO_2	98.5±1.2	36.8±0.4	47.8±0.5	100±1.0
CuO+ TiO_2	65.7±0.8	51.3±0.5	70.9±0.8	68.5±0.7
CuO+ ZnO	57.2±0.4	30.5±0.4	63.6±0.5	100±1.0
CuO+ Fe_2O_3	39.5±0.2	26.5±0.5	34.0±0.3	100±1.2
MnO_2+ NiO	58.0±0.5	42.5±0.6	75.5±1.1	29.0±0.4
MnO_2+ ZnO	45.5±0.5	23.4±0.3	22.4±0.3	92.5±0.9
MnO_2+ TiO_2	64.6±0.7	45.3±0.5	59.8±0.5	90.0±1.0
MnO_2+ Fe_2O_3	48.3±0.5	40.5±0.6	73.4±0.8	50.5±0.3
MnO_2+ SnO_2	87.5±0.9	55.5±0.7	66.5±0.9	100±1.3

From the Table-2, it can be seen that the relative catalytic activity of catalysts based on a mixture of oxides in the oxidation of combustible gases is often higher than that of catalysts based on individual oxides. From the results of the conducted research (Table-2), we can conclude that CuO + MnO_2 and CuO + SnO_2 are the most active components of the carbon monoxide catalyst.

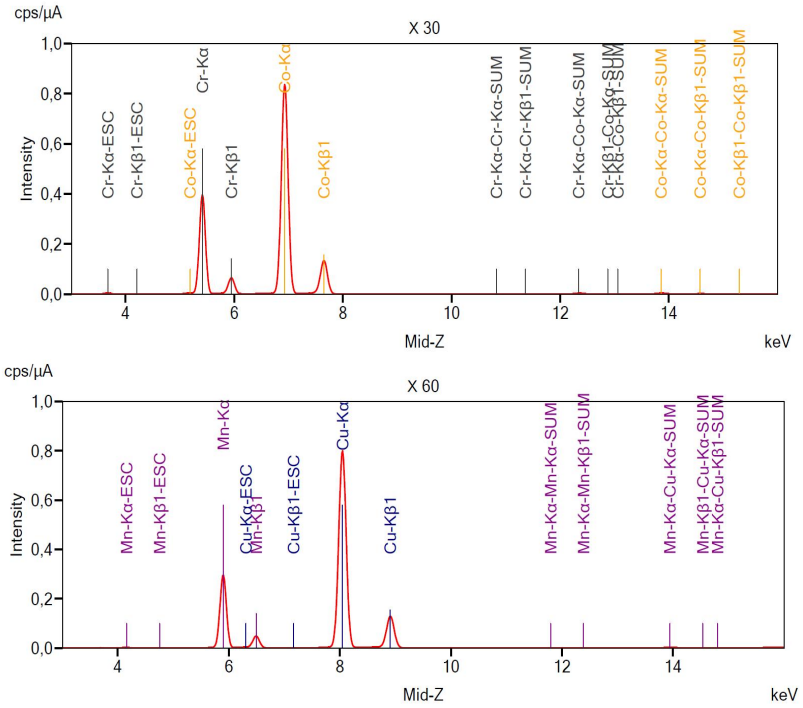


Fig.-1: ED XRF Spectra of CoO+Cr_2O_3 (75:25) Oxide Catalyst (*above*) and CuO+MnO_2 (50:50) Oxide Catalyst (*below*)

The oxidation of CO with the participation of these binary oxide mixtures reaches 100% for CuO + MnO_2 and 98.5% for CuO + SnO_2. These systems are distinguished by the highest activity in the oxidation of carbon monoxide. From the results presented in the table, the catalysts developed on the basis of the studied binary metal oxides, like gas-sensitive materials based on individual oxides, are able to effectively reduce the oxidation of CO and H_2. It can be concluded that the mixture of CH_4 and n-octane does not allow selective detection of carbon monoxide under the selected optimal conditions. Energy-dispersive X-ray fluorescence analysis results of some oxide mixtures are given in the Fig.-1. Elemental compositions of the remaining catalysts were also confirmed using energy-dispersive X-ray fluorescence spectroscopy. The results of studying the effect of the ratio of components on the activity and selectivity of catalytic systems composed of CuO-MnO_2, CoO+ZnO and CoO+Cr_2O_3 are presented in Table-3.

Table-3: The Influence of the Ratio of Catalyst Components on the Oxidation Process of Carbon Dioxide and Hydrocarbons (Temperature 350 °C)

Catalyst Content (mass %)	Oxidation degree of the component (x±Δx)%			
	CO	CH_4	n-octane	Hydrogen
CuO+ MnO_2 (95:5)	86.00	-	-	100
CuO+ MnO_2 (75:25)	100.0	4.30	6.70	100
CuO+ MnO_2 (50:50)	100.0	12.3	15.7	100
CuO+ MnO_2 (25:75)	100.0	21.3	25.7	100
CuO+ MnO_2 (5:95)	100.0	26.3	35.7	100
CoO+ZnO (95:5)	83.00	90.0	90.0	100.
CoO+ZnO (75:25)	77.50	90.0	89.0	91.0
CoO+ZnO (50:50)	35.50	88.0	87.0	91.0
CoO+ZnO (25:75)	21.50	73.0	77.0	91.0
CoO+ZnO (5:95)	15.50	62.0	72.0	91.0
CoO+ Cr_2O_3 (95:5)	85.50	81.0	96.1	100
CoO+ Cr_2O_3 (25:75)	98.50	88.0	96.5	100
CoO+ Cr_2O_3 (50:50)	100.0	91.0	97.0	100
CoO+ Cr_2O_3 (75:25)	100.0	95.0	98.0	100
CoO+ Cr_2O_3 (5:95)	100.0	94.0	98.0	100

Powder X-ray diffraction experiments on catalyst fine powders show that both components in the oxide mixture retain its phase (Fig.-2). Analysis of the powder XRD pattern of the ZnO + ZrO_2 catalyst showed that it contains 85% ZnO (mass %) and 15% ZrO_2, matching our stoichiometric ratio of precursors used to obtain this catalyst. This result clearly shows that the current methodology of catalyst preparation is conventional.

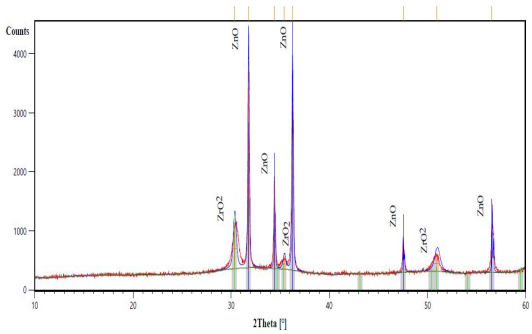


Fig.-2: Powder XRD Pattern of ZnO + ZrO_2 Catalyst

Moreover, Fourier transform infrared (FTIR) spectroscopy was used to confirm that no covalently bonded functional groups containing nonmetal–nonmetal bonds remained after catalyst preparation. This was a necessary check because nitrate, sulfate, acetate, and other salts were used during the synthesis. The FTIR spectra of both the pure metal oxide and the mixed oxide system show practically no vibrational bands above 1000 cm^{-1}, where such covalently bonded functional groups (e.g., C–O, N–O, S–O, C=O) typically appear. For example, the IR spectrum in Fig.-3 exhibits an intense absorption peak at 610 cm^{-1}, assigned to the Cr–O stretching band.

Similarly, the CoO catalyst shows a very intense and narrow peak at 600 cm^{-1}, originating from the Co–O stretching band. The absence of bands above 1000 cm^{-1} supports the conclusion that residual anions from the precursor salts were effectively removed during the preparation. The IR spectrum of oxide mixtures dominates with intense peak at 610 cm^{-1}, meaning that in that particular catalyst, contains more Cr_2O_3 (in that case 75%).

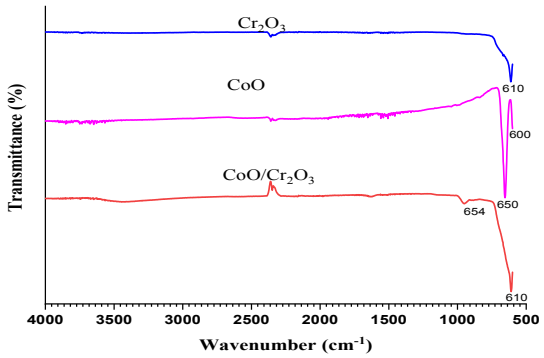


Fig.-3: FTIR Spectra of CoO + Cr_2O_3 Catalyst and Pure Oxides

The experimental results obtained in the oxidation of selected gases (Table-3) indicate that the CuO + MnO_2(75:25) composition can be used as a gas-sensitive material for a sensor designed for CO detection. In the presence of these oxides, complete (100%) oxidation of carbon monoxide is ensured at a temperature of 350 °C. However, under the selected conditions, the CuO+MnO_2 (75:25) composition system cannot ensure complete selectivity of the carbon monoxide detection process. As shown in the table, partial oxidation of CH_4 and n-octane along with CO is observed in CuO+MnO_2 (75:25) at 350 °C. In order to find a more accurate ratio of catalyst components in the process of CO oxidation with the participation of a CuO+MnO_2 catalyst, the ratio of CuO and MnO_2 was studied with a difference of 2 increments of tenth in the range of 60:40 to 80:20. Therefore, all subsequent experiments on carbon monoxide oxidation were carried out with a molar ratio of the catalyst components of 0.7CuO+0.3MnO_2. In the process of oxidation of hydrocarbons, the oxidation of soot gas in the presence of a catalyst with a composition of CoO+ZnO, which is close in activity to CoO+Cr_2O_3 (50:50), is relatively low, which negatively affects the selectivity of this catalyst. For this reason, further studies were carried out only on the example of CoO+Cr_2O_3. In subsequent experiments, the effect of the ratio of selected components of the catalyst of CoO+Cr_2O_3 on the activity of the oxidation of hydrocarbons (methane and n-octane) was studied in the ratios of CoO+Cr_2O_3 from (90:10) to 70:30. All experiments were carried out under the conditions selected above. The CoO–Cr_2O_3 oxide system with a composition of 80:20 exhibited high catalytic activity and selectivity toward hydrocarbon oxidation. Since catalyst performance is strongly influenced by the reaction temperature in most catalytic systems, the subsequent experiments were designed to evaluate the effect of temperature on the activity of the CuO–MnO_2 (0.7:0.3) catalyst during the oxidation of carbon monoxide and hydrocarbons. These studies were conducted in the temperature range of 200 - 400 °C with a temperature difference of 50 °C. The results of this study are presented in Table-4.

Table-4: Effect of Temperature on The Activity of the CuO+ Mno_2 (70:30) System in the Oxidation of Carbon Monoxide and Hydrocarbons

No.	Temperature	Oxidation degree of the component (x±ΔX). %			
		CO	CH_4	n-octane	H_2
1.	200	91.0	-	-	96.00
2.	250	100.0	-	-	100.0
3.	300	100.0	-	1.60	100.0
4.	350	100.0	4.30	6.70	100.0
5.	400	100.0	11.8	12.9	100.0

From the table, we can see the possibility of selective oxidation of carbon monoxide in the presence of

methane and n-octane using a catalyst with a composition of $CuO+MnO_2$ (0.7-0.3) at a temperature of 250 °C. Temperatures exceeding the optimum value of 250 °C resulted in reduced selectivity toward octane oxidation, whereas lower temperatures decreased the oxidation efficiency because of diminished catalytic activity. Thus, the optimal temperature for the process of carbon monoxide detection in the presence of hydrocarbons for a catalyst developed on the basis of oxides with a composition of $CuO+MnO_2$ (0.7:0.3) is found 250 °C.

CONCLUSION

The composition of the catalyst, which is highly active and selective for hydrogen from a mixture of carbon monoxide, hydrocarbons and hydrogen, has been determined, consisting of SiO_2/ZrO_2. It has been proven that the composition of the catalyst, which is highly active in the selective oxidation of CO from the exhaust gases of combustion processes at low temperatures (250ºC), corresponds to $0.7CuO+0.3MnO_2$. As a result of studying the activity and selectivity of individual and binary metal oxide catalysts in the oxidation of hydrocarbons (methane, natural gas, gasoline vapors), the activity of the mixture consisting of hydrocarbons ($0.8CoO+0.2Cr_2O_3$) is high, and it was shown that using this composition, it is possible to completely (100%) oxidize hydrocarbons at 300 ºC. These findings provide useful guidance for the design of efficient catalytic materials for exhaust gas purification and emission control. The developed catalyst systems have potential applications in environmental protection and cleaner combustion technologies. Furthermore, this study contributes to the United Nations Sustainable Development Goal (SDG-13: Climate Action) by supporting technologies aimed at reducing harmful atmospheric emissions.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-11: Sustainable Cities and Communities*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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