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X. Zhang^{1,2}, L. Komashko^{1,3}, M.K. Erkibaeva³,
A.O. Aidarova⁴, S.A. Tungatarova^{1,2}, T.S. Baizhumanova^{1,2}

¹D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry, Almaty, Kazakhstan;

²Al-Farabi Kazakh National University, Almaty, Kazakhstan;

³Pavlodar State Pedagogical University, Pavlodar, Kazakhstan;

⁴Taraz State Pedagogical University, Taraz, Kazakhstan.

E-mail: 97535110@qq.com, komashko@mail.ru, erkibaevameruert@mail.ru,
aitkul1128@mail.ru, tungatarova58@mail.ru, baizhuma@mail.ru

CATALYTIC PROCESSING OF PROPANE INTO IMPORTANT PETROCHEMICAL PRODUCTS

Abstract. In the Republic of Kazakhstan, despite the huge reserves of hydrocarbon raw materials, it is mainly consumed in the form of domestic, industrial and motor fuels, remains are burned as part of the exhaust gases, or again driven into the oil-bearing strata. Propane, which is in the composition of associated gases and formed in petrochemical, in the first case, either burned or used as fuel after separation. In the second case, it is partially used in petrochemicals, as well as municipal or motor fuel, the rest is exported. In order to identify the ability of the developed catalysts to regeneration or reoxidation and determine the energy characteristics of hydrogen and oxygen, the study was carried out by the methods TPR and TPO, as well as by TEM, XRD and BET for determine the morphology, particle size and their chemical composition. In the present work it is shown that on the developed 5%V/($\Theta+\alpha$)Al₂O₃ catalyst the process of oxidative conversion of propane passes with the formation of 24.5% ethylene and 27.5% hydrogen under the optimal conditions: 66.5% C₃H₈ + 33.5% CO₂, T = 700°C, W = 1000 h⁻¹ and C₃H₈ : CO₂ = 2 : 1.

Key words: catalytic oxidation, propane, ethylene, hydrogen, carbon dioxide.

Introduction. The world's oil reserves are decreasing every day due to the continuous production and their processing using the most modern technologies. Scientists all over the world are looking for various raw materials and methods to use the vast resources of natural gas as a substitute for petrochemicals. In this regard, considerable attention is drawn to natural gas as an alternative source of raw materials for petrochemical industries.

According to the annual Statistical Review of World Energy – 2018, published by British Petroleum (BP) at the end of 2017, proven natural gas reserves in the world are estimated at 193.5 trillion cubic meters. Kazakhstan ranks 15th in the world and 4th in the CIS of natural gas reserves. The prospects for the development of the global gas processing industry are associated with the creation and introduction of new catalytic environmentally friendly technologies for producing of olefins, based on production of polymers, alcohols and motor fuels. Gas processing plants in Kazakhstan are currently engaged mainly in the purification of gases from water, impurities of carbon dioxide and hydrogen sulfide for their use for domestic purposes. This situation is associated with the lack or absence of new catalytic technologies for the directed processing of light C₁-C₄ alkanes. There are no production facilities for the production of olefins, plastics, motor fuels and other products whose demand is met by imports. Therefore, an important task is the intensive development of the industrial processing of light hydrocarbon raw materials, the reserves of which far exceed oil reserves.

It is known that vanadium compounds [1-4] are widely used for homogeneous and heterogeneous catalysis, especially in selective oxidation of light alkanes, which are one of the most effective catalysts.

Thus, the authors of [1] investigated the activity of vanadium catalysts deposited in the oxidation of propane. It was determined that the yield of propylene was 10% with 30% conversion of propane.

In [2], V_2O_5/SiO_2 catalysts promoted by a fluoride anion and obtained by successive addition of different amounts of F-were investigated. The performance and structure of the catalysts were greatly influenced by the sequence of fluoride impregnation and the method of obtaining catalysts. Oxidative dehydrogenation of propane was carried out in a reactor with a fixed bed with a continuous flow at atmospheric pressure, a temperature range of 400 - 600°C and a ratio of gases supplied: 10% C_3H_8 : 5% O_2 : 85% Ar.

The total flow rate of the reaction gas mixture was 50 ml/min, the mass of the catalyst was 200 mg, the volume velocity was 9000 h^{-1} . For VOC-F catalyst at 540°C selectivity of propene amounted to 64.16% in the conversion of propane of 14.76%. Compared to the V-Si-O catalyst, propene selectivity increased by 9.89% and a small increase in C_3H_8 conversion was found.

Increasing atmospheric CO_2 levels have a negative impact on the environment. The chemical use of CO_2 , one of the main greenhouse gases, is an important step towards green chemistry. The main problem associated with the use of CO_2 is the thermodynamic stability of this molecule. One of the technologies that is gaining strength and importance in the scientific world is the use of CO_2 as an oxidizer for catalytic oxidative transformation at high temperatures [5-8].

Previously, we investigated the process of oxidative conversion of light alkanes into olefins in the presence of oxygen on different types of catalysts [9-18].

The paper presents the data of the activity of the developed deposited catalyst based on vanadium, capable of conducting the process of oxidative conversion of propane into ethylene and hydrogen, using CO_2 as an oxidizer.

Experimental

Catalyst preparation

The catalytic systems were synthesized by the method of impregnation in air. The developed compositions of catalysts were prepared by capillary impregnation of mixed aqueous solutions of metal salts supported on carriers by moisture capacity, followed by drying at $T = 200^\circ C$ for 2 h. Calcinations of samples at $T = 500^\circ C$ for 2 h in air was carried out for decomposition of supported metal salts and corresponding volatilization of nitrates from the catalyst surface.

Characterization techniques

Analysis of the initial mixture and the reaction products was performed using "Chromos GC-1000" (Russia) chromatograph, which was equipped with packed and capillary columns. The packed column is used for the analysis of H_2 , O_2 , N_2 , CH_4 , C_2H_6 , C_2H_4 , C_3-C_4 hydrocarbons, CO and CO_2 . A capillary column is used to analyze of liquid organic substances, such as alcohols, acids, aldehydes, ketones and aromatic hydrocarbons. Temperature of the detector by thermal conductivity – 200°C, evaporator temperature – 280°C, column temperature – 40°C. The speed of the carrier gas Ar is 10 ml / min. The chromatographic peaks were calculated from the calibration curves plotted for the respective products using the "Chromos" software for pure substances. Based on the measured areas of the peaks corresponding to the amount of the introduced substance, a calibration curve $V = f(S)$ was constructed, where V - amount of substance in ml, S - peak area in cm^2 . Concentrations of the obtained products were determined on the basis of the obtained calibration curves. The balance of regulatory substances and products was $\pm 3.0\%$.

Physico-chemical research

The specific surface area and measurement of the pore distribution of the developed catalysts were studied by the BET method (Bronauer-Emmett-Teller) on a GAPP V-Sorb 2800 analyzer (China). Nitrogen with helium was used as carrier gas. BET method was carried out at Advanced Ceramics and Composites Laboratory, Institute of Nanoscience and Nanotechnology NCSR "Demokritos" (Athens, Greece). Nitrogen with helium was used as carrier gas.

XRD analysis was performed on a Siemens Spellman DF3 diffractometer using $CuK\alpha_1$ ($\lambda = 1,5406$ Å) radiation by powder method in the angle range $2\theta = 5 - 100^\circ$.

Thermoprogrammed oxidation (TPO) and thermoprogrammed regeneration (TPR) of the developed catalysts was investigated on the analyzer "Chemosorb".

Morphology, particles size, chemical composition of initial and worked out catalysts were performed on transmission electron microscope TEM-125K with enlargement up to 66000 times by replica method with extraction and micro diffraction. Carbonic replicas were sputtered in universal vacuum station, and carrier of catalysts was dissolved in HF. Identification of micro diffraction patterns was carried out by means of ASTM cart index (Ukraine).

Results and discussion. The methods for synthesis of the developed catalysts were determined and the physicochemical characteristics of the catalysts were established. Developed 5% V/($\Theta+\alpha$)Al₂O₃ catalyst was studied by the BET, XRD, TEM, TPR and TPO methods.

The results of the studies on the determination of the surface area of the developed catalysts it is established that with increasing percentage of vanadium on the carrier equally increases the surface area of the catalytic system (figure 1).

It is known that the larger the specific surface area of the catalyst, the greater the number of active centers are on the surface, the greater the activity of the catalyst. It is assumed that this dependence is associated with the activity of 5% V/($\Theta+\alpha$)Al₂O₃ catalyst in the oxidative conversion of propane to ethylene and hydrogen under optimal reaction conditions.

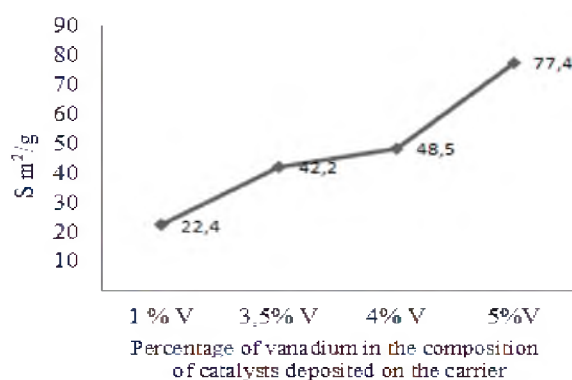


Figure 1 - Change in the specific surface area of vanadium in the composition of catalysts deposited on the carrier

Before the x-ray phase analysis of the samples, the literature sources were analyzed and the mechanisms of thermal decomposition of ammonium metavanadate and possible phases formed were determined [19.20].

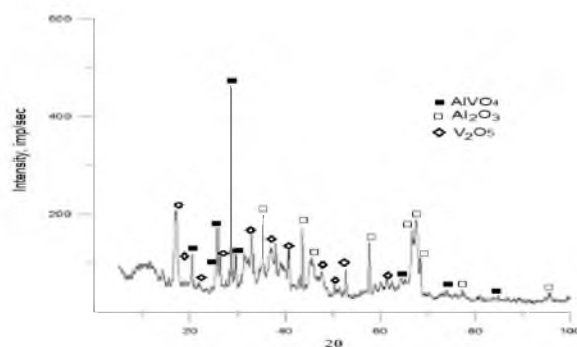


Figure 2 - XRD analysis of 5% V/($\Theta+\alpha$)Al₂O₃ catalyst

XRD analysis of 5% V/($\Theta+\alpha$)Al₂O₃ catalyst (figure 2) revealed the following phases: AlVO₄ (JSPDS, 11-0130), Al₂O₃ (JSPDS, 42-1468) and V₂O₅ (JSPDS, 41-1426). It should be noted that the phase AlVO₄ (JSPDS, 11-0130) was detected only on a single-component vanadium catalyst. It is assumed that this detected phase of the aluminum-vanadium bond promotes the formation of ethylene and hydrogen during the oxidative transformation of propane.

This conclusion is also confirmed by electron microscopic studies of catalysts. The sample is presented mainly by aggregates of translucent particles of plate type, filling a significant part of the surface of the carrier. In figure 3a shows aggregates of translucent particles, the sizes of which vary from 50-70 nm to 100-200 nm. The microdiffraction pattern is represented by a large set of symmetrical and separate reflexes and can be attributed to a mixture of phases: V_6O_{11} (JCPDS, 18-1451), V_2O_5 (JCPDS, 19-1391), $AlVO_4$ (JCPDS, 25-26).

Figure 3b shows the units of the large semi-transparent particles with a size of 100-200 nm. The microdiffraction pattern is represented by a series of reflexes and individual reflexes and can be attributed to a mixture of phases: V_2O_5 (JCPDS, 19-1391), $VOOH$ (JCPDS, 27-1366), $VO_{0.9}$ (JCPDS, 10-313).

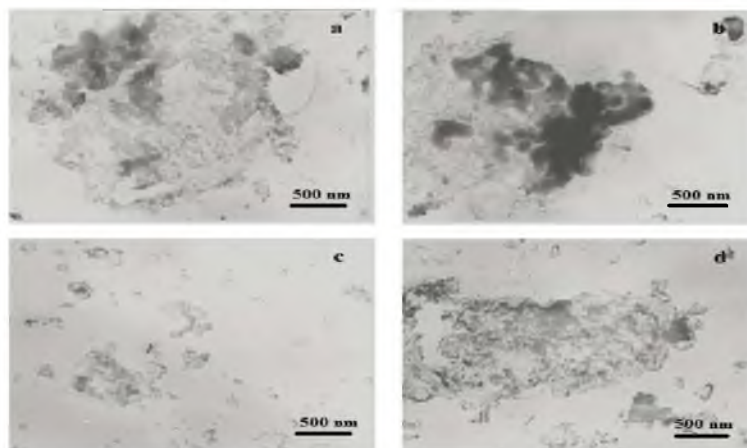


Figure 3 - TEM images of 5% V/(θ + α) Al_2O_3 catalysts

Figure 3c shows a translucent particle size of 50-100 nm, filling the surface of the carrier. The microdiffraction pattern is represented by reflexes and can be attributed to a mixture of phases: VO_2 (JCPDS, 31-1439), $VO_2 \cdot H_2O$ (JCPDS, 18-445), V_6O_{13} (JCPDS, 27-1332), V_3O_4 (34-615).

Figure 3d shows the area of dense settlement of the carrier by small particles of 20-50 nm in size. There are several large particles exceeding 150 nm. Microdiffraction pattern is represented by reflexes, located on the rings, and individual reflexes, and can be attributed to a mixture of phases: $V_7O_{17} \cdot H_2O$ (JCPDS, 15-247) и γ - VO_2 (JCPDS, 35-361).

Figure 4 shows the TPR spectrum of the vanadium catalyst. Regeneration of hydrogen was carried out in the region of 400-1000°C with four clearly defined maxima, which on the basis of TEM and literature data can be associated with successive transitions V_2O_5 in V_6O_{13} ($T_{max}^I=700^\circ C$), V_6O_{13} in VO_2 ($T_{max}^{II}=840^\circ C$), VO_2 in V_8O_{15} ($T_{max}^{III}=920^\circ C$) and then V_8O_{15} in V_2O_3 ($T_{max}^{IV}=980^\circ C$); shoulder 550°C corresponds to the regeneration weakly bound adsorbed oxygen. Theoretical calculations have shown that the amount of hydrogen absorbed in different peaks correlates well with the data of chromatographic analyses.

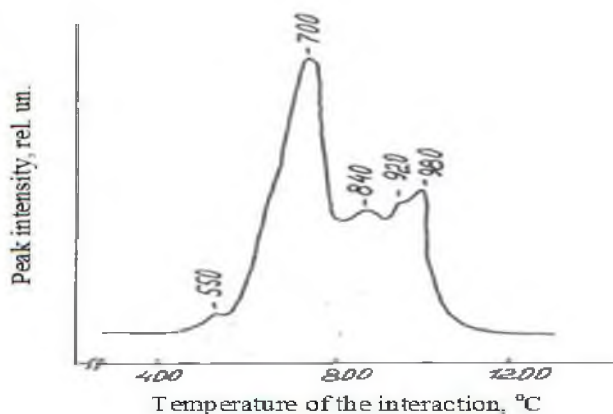


Figure 4 - TPR spectrum of 5%V/(θ + α) Al_2O_3 catalyst

It is known that the stable activity of the catalyst is ensured by the reversibility of the reduction and reoxidation processes in the surface deposited structures of vanadium oxide, so we studied the ability of the reduced catalysts to reoxidation under the influence of oxygen.

When treated with a mixture of 6% O₂+He catalyst oxygen absorption is starting from 100°C.

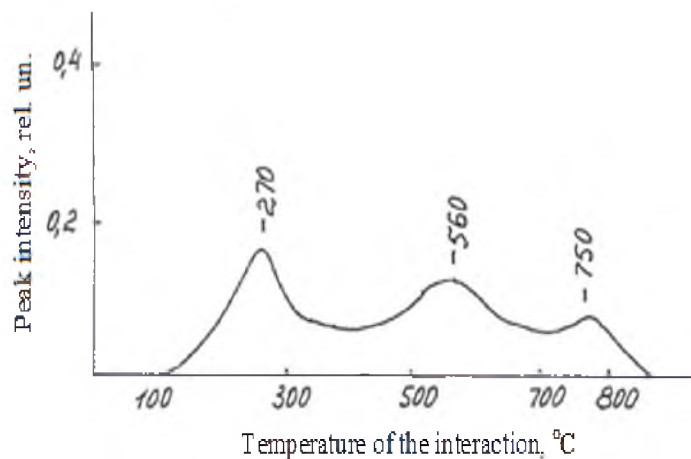
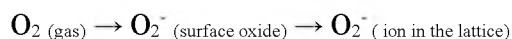


Figure 5 - TPO spectrum of 5%V/(θ+α)Al₂O₃ catalyst

It is assumed that the oxidation of reduced, coordination unsaturated vanadium oxides V⁴⁺ is with the formation of weakly adsorbed forms of oxygen and V₂O₅, as evidenced by the presence of several peaks of O₂ absorption:



From figure 5 it is seen that 5,0%V/(θ+α)Al₂O₃ the catalyst absorbs O₂ at maximum: T_{max}^I = 270, T_{max}^{II} = 560 and T_{max}^{III} = 750°C.

The paper presents data of activity of the developed 5% V/(θ+α)Al₂O₃ catalyst in the oxidation reaction of propane at W = 1000 h⁻¹ with a change in T = 500 - 800°C and the ratio of the initial gases in the reaction mixture C₃H₈ : CO₂ = 1 : 1, 2 : 1 and 5 : 1.

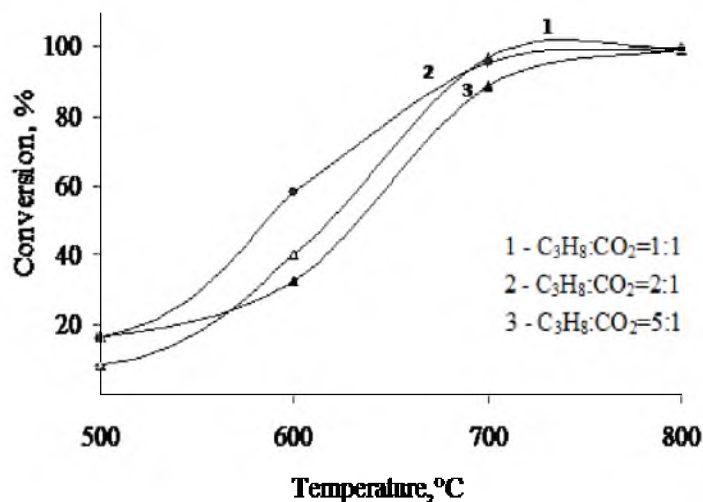
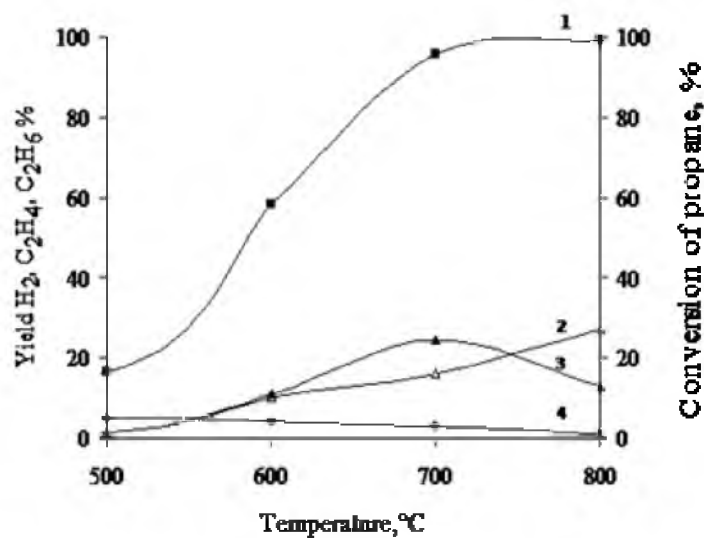


Figure 6 - Investigation of activity of 5%V/(θ+α)Al₂O₃ catalyst in the oxidation of propane at W = 1000 h⁻¹

It was found that the optimal ratio for the conversion of propane is C₃H₈ : CO₂ = 1 : 1 and C₃H₈ : CO₂ = 2 : 1.

The study of the activity of the developed 5% V/($\Theta+\alpha$)Al₂O₃ catalyst in the reaction of oxidative conversion of propane at W = 1000 h⁻¹, C₃H₈ : CO₂ = 2 : 1 showed that with an increase of the reaction temperature, the yield of ethylene increases which reaches 24.5% at T = 700°C (figure 7).



1- X_{CH₄}; 2- H₂; 3- C₂H₄; 4- C₂H₆

Figure 7 - Investigation of 5% V/($\Theta+\alpha$)Al₂O₃ catalyst activity in the reaction of propane oxidation at W = 1000 h⁻¹, C₃H₈ : CO₂ = 2 : 1

As the reaction temperature increases, the yield of ethane decreases from 4.9% to 1.0%. It is assumed that the product of the reaction of catalytic oxidation of propane - ethane during the reaction has time to oxidize to ethylene. For the formation of 27.5% hydrogen, the optimum temperature is 800°C.

Conclusion

Thus, in the present work it is shown that on the developed 5% V/($\Theta+\alpha$)Al₂O₃ catalyst using the methods of BET, XRD, TEM, TPR and TPO certain characteristics were found, namely, an increase in the specific surface area and the connection of the carrier with the active phase. It was found that the process of oxidative conversion of propane on the catalyst developed by 5% V/($\Theta+\alpha$)Al₂O₃ passes with the formation of 24.5% ethylene and 27.5% hydrogen under the optimal conditions found by the experimental method: 66.5% C₃H₈ + 33.5% CO₂ (C₃H₈ : CO₂ = 2 : 1), T = 700°C, W = 1000 h⁻¹.

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Х. Чжан^{1,2}, Л. Комашко¹, М.К. Еркибаева³,
А.О. Айдарова⁴, С.А. Тунгатарова^{1,2}, Т.С. Байжуманова^{1,2}

¹Д.В.Сокольский атындағы Жанармай, катализ

және электрохимия институты АҚ, Алматы, Қазақстан;

²Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан;

³Павлодар мемлекеттік педагогикалық университеті, Павлодар, Қазақстан;

⁴Тараз мемлекеттік педагогикалық университеті, Тараз, Қазақстан

ПРОПАНЫ МАҢЫЗДЫ МҰНАЙ-ХИМИЯ ӨНІМДЕРІНЕ КАТАЛИТИКАЛЫҚ ӨНДЕУ

Аннотация. Әлемдік мұнай қоры күн сайын заманауи технологияларды пайдалана отырып, үздіксіз өндіру және оларды қайта өңдеу есебінен азайып барады. Бүкіл әлем ғалымдары мұнай химиясын алмастырушы ретінде табиғи газдың орасан зор ресурстарын пайдалану үшін түрлі шикізат материалдары

мен әдістерін іздейді. Осыған байланысты мұнай-химия өнеркәсібі үшін шикізаттың баламалы көзі ретінде табиғи газға айтарлықтай көңіл бөлінді.

2017 жылдың соңында «British Petroleum» (BP) компаниясы жариялаған World Energy-2018 жыл сайынғы статистикалық шолуына сәйкес, әлемдегі дәлелденген табиғи газ қоры 193,5 трлн. текше метрге бағаланды. Қазақстан әлемде 15-орында және табиғи газ қоры бойынша ТМД-да 4-орында. Әлемдік газ өңдеу өнеркәсібін дамыту перспективалары полимер, спирт және мотор отындарын өндіруге негізделген олефиндерді алудың экологиялық таза каталикалық жаңа технологияларын құру және енгізуге байланысты. Қазақстанның газ өңдеу зауыттары қазіргі уақытта газды судан, көмірқышқыл газы мен күкіртсутегі қоспаларынан, оларды тұрмыстық мақсатта пайдалану үшін тазартумен айналысады. Мұндай жағдай C1-C4 жеңіл алкандарды қайта өңдеуге бағытталған жаңа каталикалық технологиялардың жетіспеушілігіне немесе жоқтығына байланысты. Мұнда олефиндер, пластмассалар, мотор отындарын және импорт есебінен қанағаттанатын басқа да өнімдерді өндіру бойынша өндірістік қуат жоқ. Сондықтан мұнай қорларынан едәуір асатын жеңіл көмірсутек шикізатын өнеркәсіптік қайта өңдеуді қарқынды дамыту маңызды міндет саналады.

Қазақстан Республикасында көмірсутек шикізатының орасан зор қорына қарамастан, ол негізінен тұрмыстық, өнеркәсіптік және моторлы отын түрінде тұтынылады, қалдықтар пайдаланылған газдардың құрамында жағылады немесе мұнай құятын қабаттарға қайта айдалады. Ілеспе газдардың құрамына кіретін және мұнай химиясында түзілетін Пропан бірінші жағдайда жағылады немесе сепарациядан кейін отын ретінде пайдаланылады. Екінші жағдайда ол ішінара мұнай химиясында, сондай-ақ коммуналдық немесе моторлы отынға пайдаланылады, қалғаны экспортқа шығады.

Жұмыста пропанның этиленге және сутекке тотығу үдерісін жүргізуге қабілетті ванадий негізінде дайындаған катализатордың белсенділігі туралы мәліметтер CO_2 тотықтырғыш қатысында жүретін реакцияға негізделген. Каталикалық жүйелер ауада сіндіру әдісімен синтезделді. Катализаторлардың дайындалған құрамы ауада $T=200^\circ\text{C}$ кезінде кептіре отырып 2 сағат, одан кейін $T=500^\circ\text{C}$ кезінде үлгілерді қыздыру арқылы ылғал сыйымдылығы бойынша тасымалдағыштарға отырғызылған металл тұздарының аралас су ерітінділерін капиллярлы сіндіру әдісімен дайындалды.

Дайындалған катализаторлар Garr V-Sorb 2800 (Қытай) талдағышында БЭТ әдісімен зерттелді. Газ тасымалдаушы ретінде гелий мен азот газдарының қоспасы қолданылды. БЭТ әдісі Наногылым және нанотехнологиялар институтының перспективалы керамикалық және композиттік материалдар зертханасында «Демокритос» (Афины, Греция) өткізілді. Рентгенқұрылымдық талдау Siemens Spellman DF3 дифрактометрінде $\text{CuK}\alpha 1$ ($\lambda = 1,5406 \text{ \AA}$) сәулеленуін қолдану арқылы $2\theta = 5 - 100^\circ$ бұрыштар диапазонында ұнтақ әдісімен жүргізілді. Термобағдарламаланған тотығу және дайындалған катализаторларды термобағдарламаланған қалпына келтіру (тотықсыздандыру) «Хемосорб» талдағышында зерттелді. Бастапқы және өңделген катализаторлардың морфологиясын, бөлшектер мөлшерін, химиялық құрамын экстракциясы және микродифракциясы бар реплик әдісімен 66000 есеге дейін ұлғайта отырып, ТЭМ-125к жарық түсіретін электрондық микроскоппен жүргізді. Микродифракциялық картиналарды сәйкестендіру ASTM cart index (Украина) индексінің көмегімен жүргізілді.

Жұмыста пропанның этиленге және сутекке тотығу үдерісін жүргізуге қабілетті ванадий негізінде әзірленген катализатордың белсенділігі туралы мәліметтер CO_2 тотықтырғыш ретінде қолданылады. Өзірленген катализаторлардың регенерацияға немесе тотығуға қабілетін анықтау және сутегі мен оттегінің энергетикалық сипаттамаларын анықтау мақсатында тпд және ТПО әдістерімен, сондай-ақ бөлшектер морфологиясын, мөлшерін және олардың химиялық құрамын анықтау үшін ТЭМ, БЭТ және РФА әдістерімен зерттеулер жүргізілді.

Осы жұмыста $5\%V/(\Theta+\alpha)Al_2O_3$ катализаторында пропанның тотығу конверсиясы үдерісі 24,5% этилен және 27,5% сутегі түзілуімен оңтайлы жағдайларда өтеді: $66,5\% \text{C}_3\text{H}_8 + 33,5\% \text{CO}_2$, $T = 700^\circ\text{C}$, $W = 1000 \text{ сағ}^{-1}$ және $\text{C}_3\text{H}_8 : \text{CO}_2 = 2 : 1$.

Түйін сөздер: каталикалық тотығу, пропан, этилен, сутегі, көмірқышқыл газ.

Х. Чжан^{1,2}, Л. Комашко¹, М.К. Еркибаева³,
А.О. Айдарова⁴, С.А. Тунгатарова^{1,2}, Т.С. Байжуманова^{1,2}

¹Институт топлива, катализа и электрохимии им. Д.В. Сокольского, Алматы;

²Казахский национальный университет им. аль-Фараби, Алматы, Казахстан;

³Павлодарский государственный педагогический университет, Павлодар, Казахстан;

⁴Таразский государственный педагогический университет, Тараз, Казахстан

КАТАЛИТИЧЕСКАЯ ПЕРЕРАБОТКА ПРОПАНА В ВАЖНЫЕ НЕФТЕХИМИЧЕСКИЕ ПРОДУКТЫ

Аннотация. Мировые запасы нефти с каждым днем сокращаются за счет непрерывной добычи и их переработки с использованием самых современных технологий. Ученые всего мира ищут различные сырьевые материалы и методы для использования огромных ресурсов природного газа в качестве заменителя нефтехимии. В этой связи значительное внимание уделяется природному газу как альтернативному источнику сырья для нефтехимической промышленности.

Согласно ежегодному статистическому обзору World Energy-2018, опубликованному компанией British Petroleum (BP) в конце 2017 года, доказанные запасы природного газа в мире оцениваются в 193,5 трлн кубометров. Казахстан занимает 15-е место в мире и 4-е место в СНГ по запасам природного газа. Перспективы развития мировой газоперерабатывающей промышленности связаны с созданием и внедрением новых каталитических, экологически чистых технологий получения олефинов, основанных на производстве полимеров, спиртов и моторных топлив. Газоперерабатывающие заводы Казахстана в настоящее время занимаются в основном очисткой газов от воды, примесей углекислого газа и сероводорода для их использования в бытовых целях. Такая ситуация связана с недостатком или отсутствием новых каталитических технологий направленной переработки легких алканов C1-C4. Здесь отсутствуют производственные мощности по производству олефинов, пластмасс, моторных топлив и других продуктов, спрос на которые удовлетворяется за счет импорта. Поэтому важной задачей является интенсивное развитие промышленной переработки легкого углеводородного сырья, запасы которого значительно превышают запасы нефти.

В Республике Казахстан, несмотря на огромные запасы углеводородного сырья, оно в основном потребляется в виде бытового, промышленного и моторного топлива, остатки сжигаются в составе отработанных газов или вновь загоняются в нефтеносные пласты. Пропан, который входит в состав попутных газов и образуется в нефтехимии, в первом случае либо сжигается, либо используется в качестве топлива после сепарации. Во втором случае он частично используется в нефтехимии, а также в коммунальном или моторном топливе, остальное идет на экспорт. Известно, что соединения ванадия широко применяются для гомогенного и гетерогенного катализа, особенно при селективном окислении легких алканов, которые являются одним из наиболее эффективных катализаторов.

В работе представлены данные об активности разработанного катализатора на основе ванадия, способного проводить процесс окислительного превращения пропана в этилен и водород, используя в качестве окислителя CO₂. Каталитические системы были синтезированы методом пропитки на воздухе. Разработанные составы катализаторов получали методом капиллярной пропитки смешанных водных растворов солей металлов, нанесенных на носители по влагоемкости, с последующей сушкой при T=200°C в течение 2 часов прокаливанием образцов при T=500°C в течение 2 часов на воздухе.

Удельную площадь поверхности и измерение распределения пор разработанных катализаторов исследовали методом БЭТ на анализаторе GAPP V-Sorb 2800 (Китай). В качестве газа-носителя использовался азот с гелием. Метод БЭТ проводился в Лаборатории перспективных керамических и композитных материалов Института наноинженерии и нанотехнологий "Демокритос" (Афины, Греция). Рентгеноструктурный анализ проводился на дифрактометре Siemens Spellman DF3 с использованием излучения CuKα1 (λ = 1,5406 Å) порошковым методом в диапазоне углов 2θ = 5 – 100°. Термопрограммированное окисление (ТПО) и термопрограммированное восстановление (ТПВ) разработанных катализаторов исследовались на анализаторе "Хемосорб". Морфологию, размер частиц, химический состав исходных и отработанных катализаторов проводили на просвечивающем электронном микроскопе ТЭМ-125к с увеличением до 66000 раз методом реплик с экстракцией и микродифракцией. Идентификация микродифракционных картин проводилась с помощью индекса ASTM card index (Украина).

С целью выявления способности разработанных катализаторов к регенерации или окислению и определения энергетических характеристик водорода и кислорода были проведены исследования методами ТПД и ТПО, а также методами ТЭМ, РФА и БЭТ для определения морфологии, размера частиц и их химического состава.

В настоящей работе показано, что на разработанном $5\%V/(\Theta+\alpha)Al_2O_3$ катализаторе процесс окислительной конверсии пропана протекает с образованием 24,5% этилена и 27,5% водорода при оптимальных условиях: 66,5% C_3H_8 + 33,5% CO_2 , $T = 700^\circ C$, $W = 1000 \text{ ч}^{-1}$ и $C_3H_8 : CO_2 = 2 : 1$.

Ключевые слова: каталитическое окисление, пропан, этилен, водород, углекислый газ.

Information about authors:

Zhang X., PhD Doctoral Student, Al-Farabi Kazakh National University, engineer of the laboratory of oxidative catalysis, JSC «D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry», Almaty, Kazakhstan. e-mail: 97535110@qq.com, <https://orcid.org/0000-0002-2819-1772>;

Komashko L., senior researcher of JSC «D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry», Almaty, Kazakhstan. e-mail: komashko@mail.ru, <https://orcid.org/0000-0002-1976-1104>;

Erkibaeva M.K., associate professor of the Department of Geography and Chemistry of Pavlodar State Pedagogical University, Pavlodar, Kazakhstan. Tel: +77182552798, e-mail: erkibaevameruert@mail.ru, <https://orcid.org/0000-0002-6586-2125>;

Aidarova A.O., Lecturer of the department of chemistry geography of Taraz State Pedagogical University, Taraz, Kazakhstan. e-mail: aitkul1128@mail.ru, <https://orcid.org/0000-0002-7163-900X>;

Tungatarova S.A., Chief Researcher, Doctor of Chemical Sciences, Laboratory of Organic Catalysis, JSC «D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry», Al-Farabi Kazakh National University, Almaty, Kazakhstan. Tel: +77272916632, e-mail: tungatarova58@mail.ru, <https://orcid.org/0000-0001-6005-747X>;

Baizhumanova T.S., Leading Researcher, Candidate of Chemical Sciences, Laboratory of Organic Catalysis, JSC «D.V. Sokolsky Institute of Fuel, Catalysis and Electrochemistry», Almaty, Kazakhstan. Tel: +77272916632, e-mail: baizhuma@mail.ru, <https://orcid.org/0000-0001-9851-264>

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