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PROCESS SIMULATION AND EVALUATION OF METHANOL RECOVERY UNIT USING ASPEN HYSYS

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Natural gas is one of the most economical and environmentally friendly energy sources, playing a crucial role in Kazakhstan’s gas industry. The optimization of gas processing technologies, particularly methanol regeneration, is essential for improving efficiency and reducing operational costs. Methanol (CH_3OH) is widely used in the oil and gas industry as a hydrate inhibitor, but its high consumption necessitates regeneration to minimize costs and environmental impact.

This study focuses on the technical and economic feasibility of methanol regeneration from methanol-water solutions (MWS) at the “X” gas processing plant in western Kazakhstan. The Aspen HYSYS software was used to simulate the methanol recovery process, employing the Peng-Robinson equation of state. The study explored different process configurations, considering separation, purification, and rectification technologies.

Keywords: Methanol-Water Solutions (MWS), Complex gas treatment plant (CGTP), The Peng-Robinson equation of state with the Stryjek and Vera modification (PRSV), Air Cooler Unit (ACU).

ASPEN HYSYS КӨМЕГІМЕН МЕТАНОЛДЫ ҚАЛПЫНА КЕЛТІРУ ҚОНДЫРҒЫСЫН ТЕХНОЛОГИЯЛЫҚ МОДЕЛЬДЕУ ЖӘНЕ БАҒАЛАУ

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Табиғи газ - Қазақстанның газ өнеркәсібінде маңызды рөл атқаратын, ең үнемді әрі экологиялық тұрғыдан тиімді энергия көздерінің бірі. Газ өңдеу технологияларын, әсіресе метанолды регенерациялау үдерісін оңтайландыру - тиімділікті арттырып, операциялық шығындарды азайту үшін маңызды. Метанол (CH_3OH) мұнай-газ саласында гидрат ингибиторы ретінде кеңінен қолданылады, алайда оның жоғары тұтыну мөлшері шығындар мен экологиялық әсерді азайту үшін оны регенерациялауды қажет етеді.

Бұл зерттеу Батыс Қазақстандағы “Х” газ өңдеу зауытында метанол-сулы ерітінділерден (МСЕ) метанолды қалпына келтірудің техникалық және экономикалық орындылығына бағытталған. Метанолды қалпына келтіру үдерісі Aspen HYSYS бағдарламасы арқылы модельденіп, Peng–Robinson күй теңдеуі қолданылды. Зерттеу барысында бөлу, тазарту және ректификациялау технологияларын қамтитын түрлі үдеріс конфигурациялары қарастырылды.

Түйін сөздер: Метанол-сулы ерітінділер (МСЕ), Кешенді газ өңдеу зауыты (КГӨЗ), Стрижек және Вера модификациясымен Пенг-Робинсон күй теңдеуі (PRSV), Ауа салқындатқыш құрылғысы (АСҚ).

МОДЕЛИРОВАНИЕ ПРОЦЕССА И ОЦЕНКА РАБОТЫ УСТАНОВКИ ИЗВЛЕЧЕНИЯ МЕТАНОЛА С ИСПОЛЬЗОВАНИЕМ ASPEN HYSYS

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Природный газ - один из самых экономичных и экологически безопасных источников энергии, играющий важную роль в газовой промышленности Казахстана. Оптимизация технологий переработки газа, в частности регенерации метанола, имеет ключевое значение для повышения эффективности и снижения эксплуатационных затрат. Метанол (CH_3OH) широко применяется в нефтегазовой отрасли в качестве ингибитора гидратообразования, однако его высокий расход требует регенерации для минимизации затрат и снижения экологического воздействия.

В данном исследовании рассматривается техническая и экономическая целесообразность регенерации метанола из метанол-водных растворов (МВР) на газоперерабатывающем заводе "Х" в Западном Казахстане. Для моделирования процесса восстановления метанола использовалось программное обеспечение Aspen HYSYS с применением уравнения состояния Пенга-Робинсона. В исследовании были рассмотрены различные конфигурации процесса, включая технологии разделения, очистки и ректификации.

Ключевые слова: Водометанольный раствор (ВМР), Установка комплексной подготовки газа (УКПГ), Уравнение состояния Пенга–Робинсона с модификацией Стрижека и Веры (PRSV), Воздушный охладитель (ВО).

Introduction. Natural gas is one of the most economical sources of fuel and energy resources, occupying a special place in the world raw material base. The reason is its high consumer characteristics, low production and transportation costs, as well as widespread use in many areas of human activity [1-3].

Great hopes are placed on natural gas as the cheapest, highly environmentally friendly fuel in preparation for the transition to the wider use of alternative non-traditional types of electricity (solar, wind, water, geothermal energy).

The gas industry of Kazakhstan is an important source of income and occupies an important place in the socio-economic development of the Republic of Kazakhstan, therefore significant funds are allocated for its development and modernization [4-7]. The development of resource-saving technologies is an important area for the oil and gas industry.

Complex gas treatment plants are a set of direct and indirect equipment designed for collecting and processing natural gas and gas condensate.

They include separation, purification, drying and cooling units, as well as booster compressor stations. When developing oil and gas fields in a sharply continental climate, it is necessary to consider the possibility of hydrate formation [8-11].

In technologies for production, treatment and transportation of oil and gas, gas hydrates because serious problems associated with disruption of these operating processes [12-13].

Gas hydrates are solid crystalline compounds that are formed under certain thermobaric conditions from an aqueous solution, ice, water vapor and low molecular weight gases. They have an appearance similar to ice or snow. Methanol (CH_3OH) is used in the oil and gas industry as a hydrate inhibitor.

In order to optimize operating costs, by reducing the volume of methanol purchases and its delivery to the point of use, methanol regeneration units are integrated into the gas treatment process, while the economic efficiency and feasibility of methanol regeneration is determined for each individual case, considering the impact various conditions and factors in the conditions present at a particular enterprise.

Materials and methods. The most optimal technology for methanol regeneration is the MWS rectification process using additional equipment for purification from mechanical impurities, salts, and hydrogen sulfide [11].

The purpose of studying the methanol regeneration

process is to determine the technical feasibility and economic feasibility of regenerating methanol from MWS released during the preparation of well fluid at the processing units of the “X” field, located in the western region of Kazakhstan.

In order to determine the technical feasibility of methanol regeneration, it is necessary to determine the quality of the base MWS, as well as the volume of purified methanol yield. Assess capital costs for the construction of a new MRU and cost-effectiveness analysis.

The methanol recovery plant was modeled to produce methanol by treating industrial wastewater from a CGTP, which is then suitable for injection into the reservoir, using the Aspen HYSYS software package, designed to study the processes of preparing oil and gas feedstocks [14-15].

The thermodynamic package used was the Peng-Robinson equation of state modified by Stryjek and Vera (PRSV), which more accurately predicts the phase behavior of hydrocarbon systems, especially systems consisting of dissimilar components.

The PRSV equation of state performs rigorous three-phase instantaneous calculations for aqueous systems containing H_2O, CH_3OH or glycols, as well as systems containing other hydrocarbons or non-hydrocarbon compounds in the second liquid phase [16-17].

Results and discussion. The goal of this process simulations was to produce the final methanol product at the “X” field gas processing plant located in the western region of Kazakhstan, with the following requirements:

- methanol (CH_3OH) - not less than 95 % wt.;

- hydrogen sulfide (H_2S) - no more than 1 ppm;

- water (H_2O) - no more than 5 % wt.

Table 1 presents the indicators for methanol concentration (% wt.) and MWS consumption (m^3/day), adopted for two options, designated as Base Option - (B1) and Alternative Option - (B2).

Table 1 - Indicators for methanol concentration (% wt) and MWS consumption

Options	Methanol concentration, % wt	MWS consumption, m^3/day
Basic option - (B1)	1.5	50
Alternative option - (B2)	1.31	8

To characterize the MWS at the inlet to the new MRU in the Aspen HYSYS program, the compositions of HC, total suspended particles (TSP) and salts for both options were specified as follows (Table 2-4):

Table 2 - Composition and properties of hydrocarbons in MWS

HC composition	Mole fractions	Mass fractions
CH_4	0.0420	0.0058
C_2H_6	0.0420	0.0108
C_3H_8	0.0699	0.0264
iso-C_4H_{10}	0.0420	0.0208
n-C_4H_{10}	0.0420	0.0208
iso-C_5H_{12}	0.0559	0.0345
n-C_5H_{12}	0.0559	0.0345
n-C_6H_{14}	0.0629	0.0464
n-C_7H_{16}	0.0559	0.0479
n-C_8H_{18}	0.0559	0.0546

n-C_9H_{20}	0.0559	0.0613
n-$C_{10}H_{22}$	0.0699	0.0851
n-C_{11}	0.0699	0.0934
n-C_{12}	0.0699	0.1018
n-C_{13}	0.0699	0.1102
n-C_{14}	0.0699	0.1186
n-C_{15}	0.0699	0.1270
Total	**1.0000**	**1.0000**

To model the properties of TSP in MWS in Aspen HYSYS, the hypothetical components (pseudo-components) tab was used.

The Aspen HYSYS library allows you to create hypothetical components to describe hydrocarbon feedstocks. In the calculations, kaolin was used as a hypothetical component, having a molar mass of 258.0 and a density of 2600.0 kg/m^3, as the most suitable component in terms of characteristics (Table 3).

Table 3- Composition and properties of TSP in MWS

Composition	**Mole fractions**	**Mass fractions**
TSP	1.0000	1.0000
Properties		
Molecular weight*	258.0	
Density (kg/m^3)	2600.0	
Diameter (mm)	1.000	

**hypothetical component - kaolin*

Table 4- Composition of salts in MWS

Composition	**Mole fractions**	**Mass fractions**
NaCl	0.7085	0.5000
Na_2SO_4	0.2915	0.5000

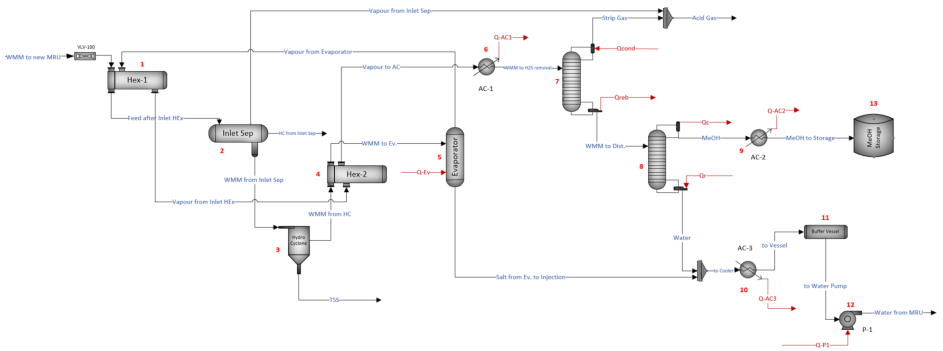


Fig.1 - Process diagram of the new MRU for option B1

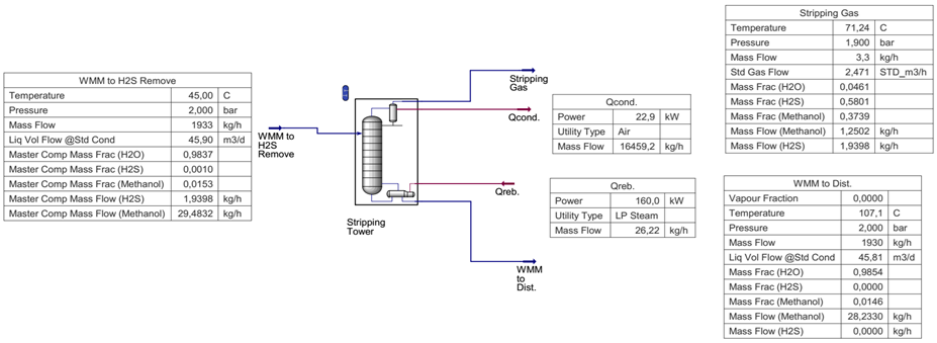


Fig.2 - Parameters of the stripping column for H_2S removal of the new MRU, according to B1 option

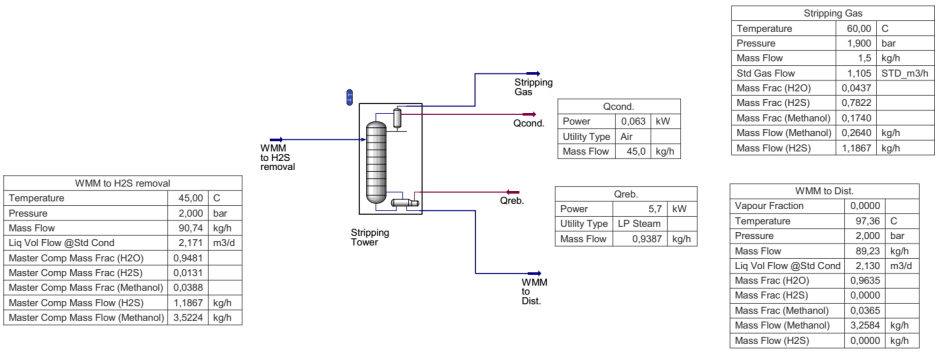


Fig.3 - Parameters of the stripping column for H_2S removal of the new MRU, according to B2 option

When modeling the new MRU, the need to remove such undesirable components as hydrocarbons, salts, TSP and H_2S from the input flow of the MWS was considered. The design of the new MRU was supplemented with the following equipment: a three-phase separator with a filter-coalescer for removing hydrocarbons, a hydrocyclone for removing TSP, an evaporator for removing salts, a stripping column for removing H_2S.

The final process diagrams of the new unit for the two options are identical, in Fig.1 shows a diagram of the new MRU only for the basic version (B1). The operating parameters of the stripping column for two options are shown in Fig.2-3.

Saturated MWS with a pressure of about 2.7 bar after the reducing valve and a temperature of about 31.5 °C enters the input heat exchanger-heater MWS HEx-1 “steam-liquid” (1), in which it is heated to approximately 94.50 °C so that improve the separation of MWS from hydrocarbons carried away from the process lines of the gas treatment plant. After heating in HEx-1, the MWS enters the separator V-102 (2), which is also equipped with a coalescer filter for more complete removal of hydrocarbons from the MWS, since even a small number of dissolved hydrocarbons can form stable emulsions with the aqueous phase of the MWS. The pressure in the separator V-102 is maintained at 2.5-2.55 bar abs. At the same time, the separator V-102 serves to remove light hydrocarbon gases if they were captured by the MWS flow. It is assumed that the captured hydrocarbons, under their own pressure, are periodically discharged into the closed drainage system of the gas treatment plant, and the MWS enters the hydrocyclone (3) to remove the suspended solids, which are discharged from the bottom of the hydrocyclone. The MWS after the hydrocyclone passes through the HEx-2 heat exchanger (4), where it is heated to 105 °C before entering the evaporator (5). The evaporator inside is equipped with a tube bundle into which water vapor (or any other heat-transfer medium) with a temperature of about 130-135 °C is supplied, which heats the MWS to 130 °C, transferring the MWS to a completely vapor phase. In this case, the salts are removed from the bottom of the evaporator in the form of a brine solution. The MWS vapor stream leaving the evaporator preheats the MWS input stream in HEx-1 and the MWS stream before the evaporator in HEx-2.

Before entering for regeneration, dissolved H_2S must be removed from the MWS, because product methanol

should not contain this extremely undesirable, highly toxic and corrosive component. To remove H_2S, an evaporation column (7) is installed, consisting of the column itself, as well as:

- top of the condenser column (ACU (6) or water cooler), reflux tank and reflux return pump;

- the bottom of the reboiler column for heating the bottom liquid (water vapor can act as a heating agent).

It is also possible to use hot oil as a heating agent, or to heat the bottom liquid directly in a fire heater: both of these options require fuel gas.

MWS with a pressure of 2 bara and at a temperature of 45 °C enters the upper part of the evaporation column. According to calculations, the temperature of the upper product of the evaporation column after the reflux tank was 71.24 °C, the pressure was 1.9 bar, and the temperature of the bottom liquid was 107 °C. H_2S with some water vapor, about 1.9-2 % wt., after a reflux tank of 59.304 Sm^3pd (79.2 kg/day is discharged to the Low-Pressure Flare). Since the volume of gas after the stripper column is very small, this should not have a significant impact on greenhouse gas emissions.

The MWS from the bottom of the evaporation column with a temperature of 107 °C enters the middle part of the distillation column (8). Methanol is regenerated by rectification at a pressure of 1.9 bara and 2 bara and temperatures of 86 °C and 120 °C at the top and bottom of the column, respectively. The upper product of the column is methanol with a purity of at least 95 % wt., the lower product is water (99.99 % wt.) with a methanol concentration of no more than 0.01 % wt. Water from the bottom of the column is discharged into the drainage system, and the regenerated methanol, having passed through the air cooler (9), where it is cooled to 45 °C, and the reflux tank is further supplied to the corresponding tank at the chemical reagent storage site (13). Part of the regenerated methanol after the reflux tank is supplied to the top of the column for reflux using a reflux pump.

Additional pumps for pumping product methanol into the storage tank and bottom water into the drainage system are not needed, since the flow pressure is ~1.8 and 1.85 bara, respectively, is sufficient for pumping.

Since the water from the bottom of the column is already a fairly pure product, it can be introduced into the recycling cycle.

According to the modeling results, the methanol product meets the specification requirements (Table 5).

The simulation results were used to estimate capital costs according to AACE Class 5 [18].

Table 5 - Methanol Product Specifications

Methanol to storage	**Options**	
	B1	B2
Temperature, °C	45	45
Pressure, bar	1.55	1.55
% Methanol recovery	83.1	77.2
Mass flow, kg/h	27.71	3.58
Methanol, % wt	95	95
Water, % wt	5	5
H_2S, % wt	0	0

At each stage of project implementation, the error of the calculated budget is specified, according to the AACE methodology, which is assigned a class:

- from the first class with an error of 10 % / 15 %,

- up to grade 5 with an error of 50 % / +100 %.

Capital costs were calculated in the ASPEN Process Economic Analyzer (APEA) software package, based on modeling the operating process of the new MRU, with the definition of a list of main equipment (Table 6).

Table 6 - List of main equipment

No.	Item number	Name	Description	Quantity, units
Heat exchange equipment				9
1	1	HE-1	Input heater MWS	1
2	4	HE-2	MWS heater in front of the evaporator	1
3	6	AC-1	Air MWS cooler	1
4	9	AC-2	Air methanol product cooler	1
5	10	AC-3	Air water cooler	1
6	7.1	C-Str	Stripper condenser	1
7	8.1	C-Dist	Distillation column condenser	1
8	7.2	R-Str	Stripper reboiler	1
9	8.2	R-Dist	Distillation column reboiler	1
Capacitive equipment				1
1	11	Buffer Vessel	Water buffer capacity	1
Separation equipment				7
1	2	Inlet Separator	Input separator MWS	1
2	5	Evaporator	Evaporator MWS	1
3	7.3	RV-1	Reflux tank of stripper column	1
4	8.3	RV-2	Reflux tank of distillation column	1
5	7	Stripping column	Stripping column	1
6	8	Distillation col.	Distillation column	1
7	3	Hydrocyclone	Hydrocyclone removal of TSP	1
Pumps				3
1	12	P-1	Water pump	1
2	7.4	RP-1	Stripper Reflux Pump	1
3	8.4	RP-2	Distillation Column Reflux Pump	1
Storage containers				1
1	13	MeOH Storage	Methanol storage tank	1
Total units of equipment				**21**

Based on the simulation of the operating process, the capital costs for the acquisition of a block-modular MRU were determined, considering the main equipment, materials and costs for the manufacture of modules (Table 7). When calculating the total cost of the project, considering the average complexity and level of uncertainty for this stage, based on the Operator's capital cost calculation standards, the following assumptions were made to increase the base estimate:

- 40 % allowance for possible unaccounted indicators for the items "Equipment" and "Construction and installation work";

- 30 % contingency for all cost items.

Table 7- Results of calculating the cost of manufacturing a block-modular MRU

Name of costs	Cost according to B1*	Cost according to B 2*
Equipment	571 739	450 061
Pipelines	777 477	408 296
Construction Materials	699 031	493 684
Steel products	68 145	63 348
Automation	1 578 052	1 389 855
Electrical equipment	981 802	979 736
Insulation	236 172	93 602
Painting	103 977	70 116
Total	**5 016 395**	**3 948 699**

**Prices are in US dollars.*

General and administrative expenses are assumed to be 15 % of the total procurement and construction costs. The results of calculating capital costs are presented in Table 8.

Table 8 - Results of calculating capital costs for project implementation by options

Engineering	Cost according to B1*	Cost according to B2*
Basic Design	985 877	626 943
Detailed design	1 834 647	1 507 897
Equipment	6 011 160	4 925 825
Manufacturing costs	2 227 628	1 614 863
Construction and installation works	3 293 171	1 919 150
General and administrative expenses	1 331 037	975 620
Total for the Project	**15 683 520**	**11 570 297**

**Prices are in US dollars.*

Table 9 - Economic assessment results

Indicators	B1	B2
Calculation period	2023-2037	
Cumulative volume of methanol production, thousand tons	5.99	3.74
Annual methanol production, t	570.00	356.00
Total cost of recovered methanol for the calculation period, million US dollars	6.47	4.04
OPEX MOD, million US dollars	-1.84	-1.36
CAPEX MOD, USD million	-16.72	-12.33
NPV @10, million US dollars	-10.13	-7.80
Break-even analysis		

CAPEX, USD	2 566 657	1 722 828
Methanol price, USD/t	5 172	6 132
Methanol volume, t/g.	3 229	3 010

Based on the results of calculating capital costs, an assessment of economic efficiency was made with the following indicators (Table 9).

The economic assessment of the project with accepted forecast operational and current macroeconomic parameters and cost assumptions shows:

- positive results (NPV≥0) with CAPEX not exceeding USD 2.6 million (base scenario) and USD 1.7 million (alternative scenario);

- positive results (NPV≥0) with a methanol price of at least 5 172 USD/t (base scenario) and 6 132 USD/t (alternative scenario);

- positive results (NPV≥0) with an annual methanol production volume of at least 3.2 thousand tons/year (base scenario) and 3 thousand t/year (alternative scenario).

Conclusions. When modeling the existing methanol removal scheme, we found that the recovery rate was insufficient. To increase the efficiency of regeneration, it is necessary to supplement the process diagram with additional equipment for purification from mechanical impurities, salts, and hydrogen sulfide.

We have determined the optimal technical and process parameters of the distillation column and hydrogen sulfide removal column. The product of the regeneration unit is a saturated 95 % methanol solution.

The study allowed us to determine the following:

1. From an engineering point of view, the regeneration of methanol in CGTP conditions is quite feasible.

2. Rectification of MWS is by far the most developed and widespread technology. There are a significant number of companies on the market that have extensive experience in the design and manufacture of MRU using the rectification method.

3. The average annual yield of regenerated methanol at the specified volumes of MWS and methanol concentration will be: option B1 – 570 t/year, option B2 - 356 t/year.

4. The low concentration of methanol in the MWS is due to the existing technological process, which allows only a small amount of methanol to be recovered from the process streams. The main volume of methanol is carried away with gas (about 15-20 %) and condensate (70-75 %).

5. A prerequisite for the regeneration of methanol in CGTP conditions is at field “X” is the need for preliminary preparation of the MWS with the mandatory removal of hydrocarbons, mechanical impurities and acid gases.

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References

1. Zanne M., Grčić M. Challenges of LNG (Liquefied Natural Gas) Carriers in 21” Century // Promet-Traffic & Transportation. - 2009. - Vol.21 (1).- P.49-60. DOI 10.7307/ptt.v21i1.912.

2. Mohammad N., Ishak W. W. M., Mustapa S. I., Ayodele B. V. Natural Gas as a Key Alternative Energy Source in Sustainable Renewable Energy Transition: A Mini Review // Front. Energy Res. -2021. - 9:625023. DOI 10.3389/fenrg.2021.625023.

3. Kang D. W., Lee W., Ahn Y. H., Kim K., & Lee J. W. Facile and sustainable methane storage via clathrate hydrate formation with low dosage promoters in a sponge matrix // Energy. - 2024. -Vol.292:130631. DOI 10.1016/j.energy.2024.130631

4. Chakeeva K. S., Mombekova G. R., Kuzenbayeva E. R. The current state of the oil and gas industry of the Republic of Kazakhstan//State Audit.- 2023. -Vol.2(59). - P.107.-117. DOI 10.55871/2072-9847-2023-59-2-107-117

5. Imangozhina Z.A. Sovremennoe sostojanie gazovoj otrasli Respubliki Kazahstan// Vestnik universiteta Turan. -2021.-№ 1 (89) - S.201-208. DOI 10.46914/1562-2959-2021-1-1-201-208. [in Russian]

6. Kaiser, M. J., & Pulsipher, A. G. A review of the oil and gas sector in Kazakhstan // Energy Policy.- 2021.- Vol.35 (2). - P.1300 - 1304. DOI 10.1016/j.enpol.2006.03.020

7. Maldynova A., Bodaukhan G., Aitkhojayeva G., Ilyas A., B. Murzabekova. Innovative Potential of the Oil and Gas Industry of Kazakhstan // Eurasian Journal of Economic and Business Studies. - 2023. - Vol.67 (2). - P.33-34. DOI 10.47703/ejebs.v2i67.253

8. Besley D., Kohli S., Rahardja S., Knight D., Farole T., Collier J. B., et.al. “Country Climate and Development Report (CCDR): KAZAKHSTAN,” The World Bank Group, 1818 H Street NW, Washington, DC 20433, 2022. [Online]. Available: https://documents1.worldbank.org.- Date of address: 26.05.2025

9. Aregbe A. Gas Hydrate-Properties, Formation and Benefits // Open Journal of Yangtze Oil and Gas. - 2017.- Vol.2 (1). - P.27. DOI 10.4236/ojogas.2017.21003

10. You K., Flemings P. B., Malinverno A., Collett T. S., Darnell K. Mechanisms of Methane Hydrate Formation in Geological Systems // Reviews of Geophysics. - 2019.- Vol.57(41). - P.1146. DOI 10.1029/2018RG000638

11. Satenov K. G., Tkenbayev S. M., Tashenov Z. A., Akhmetov Z. E., Kadyrov S. R. Kazakhstan journal for oil & gas industry. - 2024.- Vol. 6 (1).- P.99. DOI 10.54859/kjogi108691 [in Russian]

12. Sayed A. E.-R., Ashour I., Gadalla M. Integrated process development for an optimum gas processing plant // Chemical Engineering Research and Design. - 2017. Vol.124.-P.114-123. DOI 10.1016/j.cherd.2017.05.031

13. Mazumder M., Xu Q. Modeling and Optimization for a Comprehensive Gas Processing Plant with Sensitivity Analysis and Economic Evaluation //Chemical Engineering & Technology. - 2020. -Vol.43 (11). - P. 2198-2207. DOI 1002/ceat.202000216

14. Teixeira A. M., Arinelli L. de O., de Medeiros J. L., de Q. F. Araújo O. Recovery of thermodynamic hydrate inhibitors methanol, ethanol and MEG with supersonic separators in offshore natural gas processing // Journal of Natural Gas Science and Engineering. - 2018. - Vol.52. - P.186-186. DOI 10.1016/j.jngse.2018.01.038

15. Yang Xiao, Shengbin Wu, Hantao Xia, Jinyuan Zhang, Lingling Ding, Xiaolong Bao, Yi Tang, Yongjie Qi. Simulation of and multi-aspect study of a novel trigeneration process for crude helium, liquefied natural gas, and methanol production; operation improvement and emission reduction // Fuel.-2023.- Vol.347: 128402. DOI 10.1016/j.fuel.2023.128402

16. Stryjek R., Vera J. H. PRSV: An Improved Peng-Robinson Equation of State for Pure Compounds and Mixtures // Canadian Journal of Chemical Engineering.-1986.- Vol.64 (2).- P.323-333. DOI 1002/cjce.5450640224

17. Proust P., Vera J. H. PRSV: The Stryjek-Vera modification of the Peng-Robinson equation of state. Parameters for other pure compounds of industrial interest // Canadian Journal of Chemical Engineering.- 1989.-Vol.67 (1). - P.170-173. DOI 10.1002/cjce.5450670125

18. AACE International Recommended Practice No.18R-97: Cost Estimate Classification System-As Applied In Engineering, Procurement, And Construction For The Process Industries. AACE International – 2005. URL: https://library.aacei.org/pgd01/pgd01.shtml. Date of address: 26.05.2025

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