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DEHYDRATION OF NATURAL GAS WITH VARIOUS ADSORBENTS AND DETERMINATION OF THE EFFICIENCY OF AN ADSORBER WITH A MULTILAYER ADSORBENT BED FOR GAS DEHYDRATION

Makhmudov Mukhtor Jamolovich
Bukhara State Technical University, Bukhara 200100, Uzbekistan
E-mail: makhmudov.mukhtor@inbox.ru
Nematov Khusan Ibodullayevich
Karshi State Technical University, Karshi 180000, Uzbekistan
Khujakulov Aziz Fayzullayevich
Bukhara State Technical University, Bukhara 200100, Uzbekistan
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Shoymardonov Olmasbek Bolta ogli
Karshi State Technical University, Karshi 180000, Uzbekistan
Sunatov Shokhrukh Shamsi ogli
Bukhara State Technical University, Bukhara 200100, Uzbekistan
Rakhimov Zakhriddin Zafar ogli
Bukhara State Technical University, Bukhara 200100, Uzbekistan

Abstract. The selection of adsorbents for natural gas dehydration, the evaluation of their adsorption capacity and degree of dehydration under dynamic conditions, and the development of both the conditions for natural gas dehydration in a composite adsorbent bed and the design of the adsorber are all pressing challenges today. It is known that methane forms hydrate crystals with a linear structure, ethane forms spiral and atypical structures, and propane forms branched and disordered structures. Considering this, natural gases containing various hydrocarbons form mixed hydrate crystals with a complex, branched structure. This article presents the results of a study determining the dehydration efficiency of wet raw natural gas using composite adsorbent beds of silica gel, aluminum oxide, and zeolites. Based on the results obtained, a proposal is made to change the design of the single-bed adsorber used for gas dehydration to a multi-bed design.

Keywords: natural gas, gas hydrate, silica gel, aluminum oxide, zeolite, adsorption

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Annotatsiya. Tabiiy gazni suvsizlantirish uchun adsorbentlarni tanlash, ularning adsorbsion qobiliyatini va dinamik sharoitlarda suvsizlanish darajasini baholash, kompozitsion adsorbent qatlamida tabiiy gazni suvsizlantirish sharoitlarini ishlab chiqish va adsorberni loyihalash bugungi kunda dolzarb muammolardir. Ma'lumki, metan chiziqli tuzilishga ega gidrat kristallarini hosil qiladi, etan spiral va atipik tuzilmalarni hosil qiladi, propan esa shoxlangan va tartibsiz tuzilmalarni hosil qiladi. Buni hisobga olsak, turli uglevodorodlarni o'z ichiga olgan tabiiy gazlar murakkab, tarvaqaylab ketgan tuzilishga ega aralash gidrat kristallarini hosil qiladi. Ushbu maqolada silikagel, alyuminiy oksidi va zeolitlardan tashkil topgan kompozit adsorbent qatlamlari yordamida nam xom tabiiy gazni suvsizlantirish samaradorligini aniqlash bo'yicha tadqiqot natijalari keltirilgan. Olingan natijalarga asoslanib, gazni suvsizlantirish uchun ishlatiladigan bir o‘rinli adsorber konstruksiyasini ko‘p o‘rinli konstruksiyaga o‘zgartirish taklifi kiritildi.

Kalit so‘zlar: tabiiy gaz, gaz gidrati, silikagel, alyuminiy oksidi, zeolit, adsorbsiya.

Аннотация. Выбор адсорбентов для осушки природного газа, оценка их адсорбционной способности и степени осушки в динамических условиях, а также разработка как условий осушки природного газа в слое композитного адсорбента, так и конструкции адсорбера - все это насущные задачи на сегодняшний день. Известно, что метан образует гидратные кристаллы с линейной структурой, этан образует спиральные и нетипичные структуры, а пропан образует разветвленные и неупорядоченные структуры. Учитывая это, природные газы, содержащие различные углеводороды, образуют смешанные кристаллы гидратов со сложной разветвленной структурой. В данной статье представлены результаты исследования, в котором определялась эффективность обезвоживания влажного природного газа-сырца с использованием слоев композитного адсорбента из силикагеля, оксида алюминия и цеолитов. На основании полученных результатов предложено изменить конструкцию однослойного адсорбера, используемого для осушки газа, на многослойную конструкцию.

Ключевые слова: природный газ, газогидрат, силикагель, оксид алюминия, цеолит, адсорбция

1. INTRODUCTION.

Natural gas is one of the key components of the national economy and the fuel and energy sector worldwide. At the same time, it is a valuable raw material resource for the chemical industry [1]. The main advantages of gaseous fuels

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include their low-cost transportation through pipelines without the need for rail or water transport, the use of relatively simple processing technologies compared to other raw materials, and the significantly lower amount of toxic gases released during combustion [2]. These advantages have led to a growing demand for natural gas. Therefore, the development and improvement of processes aimed at enhancing the quality of natural gas are of great importance.

Around the world, extensive scientific research is being conducted to improve natural gas purification and dehydration processes and to develop modern combined methods for these purposes. In this regard, the dew point of commercial gas is one of the main regulated quality indicators [3, 4]. The presence of moisture in natural gas significantly affects pipeline corrosion during transportation and storage, the stable operation of automatic control equipment, compressor stations, and other technological systems. Therefore, particular attention is being paid to the development and implementation of technologies that improve natural gas dehydration processes, especially adsorption drying processes and the efficiency of the adsorbents used in them [5].

Gas humidity refers to the presence of water vapor in the gas. The moisture content of natural gas depends on pressure and temperature. The higher the gas temperature, the more moisture it can retain per unit volume. Pressure has an inverse effect: as gas pressure increases, its moisture content decreases [6-7].

Water vapor can saturate a gas up to the saturated vapor pressure corresponding to a given temperature. If this limit is exceeded, condensation occurs, and the vapor transforms into a liquid phase.

The temperature at which a gas becomes fully saturated with water vapor is called its dew point [8]. The presence of moisture in gas causes corrosion of pipeline systems during transportation and leads to the formation of hydrates and condensates in gas pipelines. In addition, moisture reduces the heating value of the gas. Therefore, gases are dried using solid or liquid absorbents [9]. However, the development of advanced technologies aimed at the complete removal of moisture from gas, particularly through adsorption processes, continues to this day [10, 11].

Gas humidity is classified into three types: relative, specific, and absolute humidity [12].

Absolute humidity is the mass or quantity of water vapor, expressed in grams, contained in a unit volume of gas. The unit of absolute humidity is g/m^3 [13].

Specific humidity is the mass of water vapor contained in a unit mass of wet gas. The unit of specific humidity is g/kg [14].

Relative humidity represents the percentage of the maximum amount of water vapor that can be absorbed by the gas at a given pressure and temperature.

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Relative humidity (φ) is measured as a percentage and is calculated as the ratio of the partial pressure of water vapor, ρ, to the saturated vapor pressure, P, at the same temperature [15]:

$$\varphi = \frac{p}{P}$$

For a saturated gas, the relative humidity is equal to 1 (or 100%) [16].

The dew point of hydrocarbon gases consisting of mixtures of simple gases depends on their composition and pressure.

The moisture content of a gas can be determined using the gravimetric method. This method is based on passing a measured volume of gas through a moisture-absorbing substance and determining the absorbed moisture by measuring the increase in the absorbent's weight. Calcium chloride or its mixture with phosphorus pentoxide is commonly used as the absorbent. Since the moisture-holding capacity of gas depends on temperature and pressure, moisture measurements should be carried out under the same conditions in which the gas is intended to be used [17].

Knowing the absolute humidity of the gas, it is possible to determine the dew point of the gas in the pipeline at the corresponding pressure.

1.1. Gas Hydrates and Conditions for Their Formation.

During the production and transportation of gas saturated with moisture, gas hydrates may form (Figure 1) [18, 19, 20]. Gas hydrates are chemical compounds of gases and water that resemble ice in appearance.

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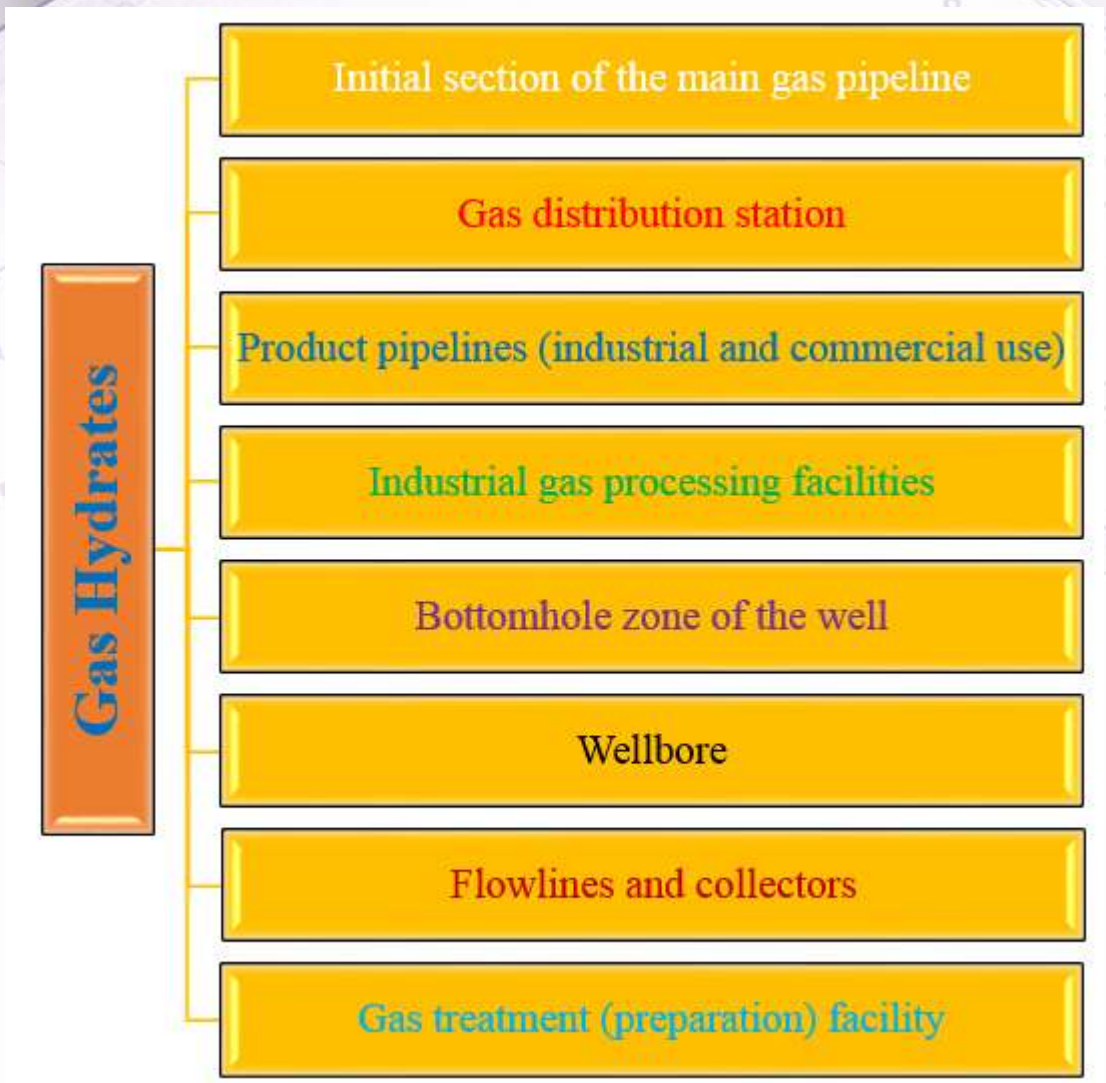


Figure 1. Gas Industry Systems in Which Hydrate Formation Occurs

Hydrocarbon hydrate crystals are formed when hydrocarbons interact with water at a relative humidity of $\varphi > 0.6$ [21]. These hydrates can cause blockages in gas pipelines, pressure control valves, and shut-off systems. The general composition of hydrate crystals is expressed as [22]:

$$\boldsymbol{M \cdot H_2O}$$

where: M – hydrocarbon molecule.

Methane forms hydrates with water in the form of $CH_4 \cdot H_2O$ [23], ethane forms $C_2H_6 \cdot H_2O$ [24], and propane forms $C_3H_8 \cdot H_2O$ hydrates [25].

Gas hydrates can form at temperatures significantly higher than the freezing point of water [26].

The structure of gas hydrates consists of water molecules arranged in an ice-like open framework containing cavities of two different sizes (large and small), as shown in Figure 2 [27, 28-30].

These cavities are relatively large and may be partially or completely occupied by gas molecules. The degree of cavity occupancy depends on intermolecular interactions and thermobaric conditions.

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The stability of natural gas hydrates is generally maintained within a temperature range of –5 to 10°C [31, 32] and a pressure range of 6 to 20 kgf/cm² [33]. At higher temperatures and lower pressures, gas hydrates do not form [34].

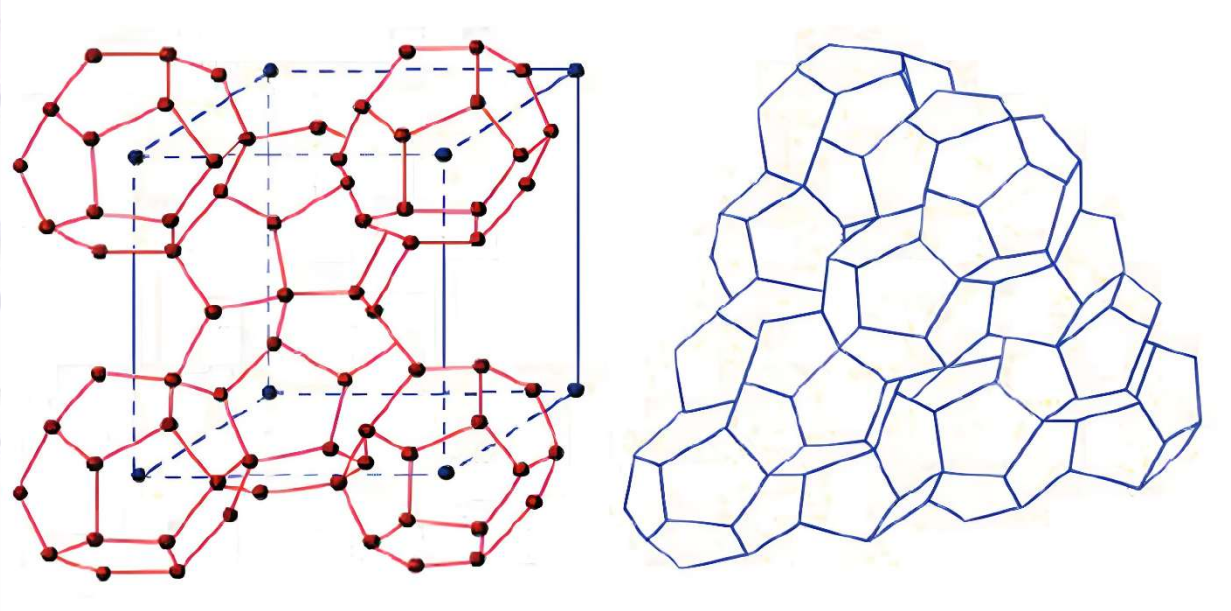


Figure 2. Structure of Gas Hydrates

For individual gases, there is an upper temperature limit above which hydrate formation cannot occur regardless of the pressure applied. This temperature is known as the critical hydrate formation temperature. It is 21.5°C for methane [35], 14.5°C for ethane [36], and 5.5°C for propane [37].

The dependence of hydrate formation by ethane and propane on pressure and temperature is presented in Table 1 [38, 39, 40].

Table 1

Hydrate Formation Conditions

Ethane		Propane	
Temperature, °C	**Pressure, MPa**	**Temperature, °C**	**Pressure, MPa**
-9,5	0,5	-11,9	0,10
-6,7	0,36	-9,0	0,12
-3,9	0,41	-6,3	0,13
-1,1	0,46	-5,6	0,13
0,6	0,51	-3,3	0,16
1,7	0,58	-1,0	0,17
10,8	1,70	1,7	0,24
13,0	2,70	2,3	0,27
14,5	3,40	3,3	0,34
-	-	4,4	0,41
-	-	5,5	0,48

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The heavier the hydrocarbon gas, the faster it forms hydrates in the presence of moisture.

The conditions for hydrate formation in wet gas can be explained graphically. Figure 3 [41] illustrates the conditions under which hydrate crystals form in wet gas for individual hydrocarbons. In the figure, line AD represents the vapor-pressure curve of an individual hydrocarbon. The region to the left of line BC corresponds to the hydrate formation zone, whereas the region to the right represents the hydrate-free zone [41].

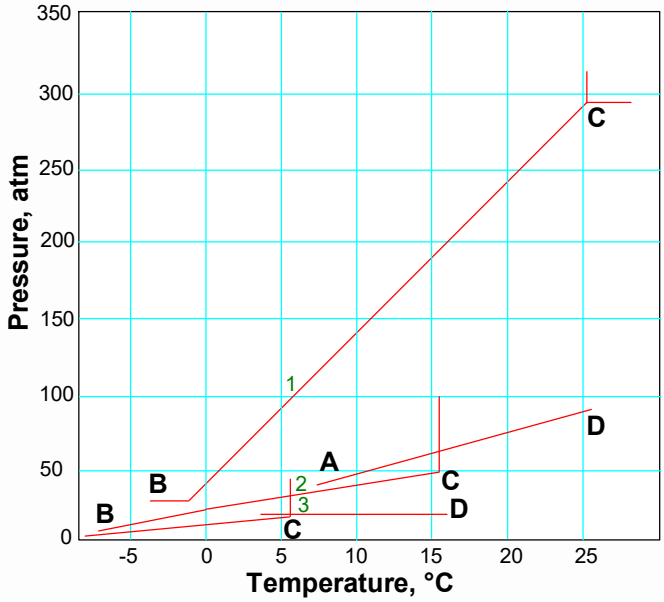


Figure 3. Conditions for the Formation of Hydrate Crystals in Wet Gas for Individual Hydrocarbons: *1 – Methane, 2 – Ethane, 3 – Propane*

Point C indicates the critical hydrate formation temperature. At temperatures above this value, hydrates cannot form regardless of the pressure applied [39]. The formation of gas hydrates can be prevented by several methods [40, 41, 42, 43, 44]:

- Preheating the gas to maintain its temperature above the hydrate formation temperature. This method is mainly used in gas distribution stations and gas processing facilities as part of their technological schemes [42].
- Reducing the pressure in gas pipelines below the hydrate equilibrium pressure. However, this method is economically costly, as it significantly reduces the pipeline's transportation capacity [43].
- Injecting hydrate inhibitors into gas pipelines. Common inhibitors include methanol, diethylene glycol (DEG) [44], triethylene glycol (TEG) solutions [45], and calcium chloride [46, 47]. The introduction of these inhibitors into the gas stream allows them to partially absorb water vapor and convert it into solutions that either do not form hydrates or form hydrates only at lower temperatures.

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In main gas pipelines, methanol is most commonly used to remove existing hydrate plugs or prevent their formation. In this case, methanol is typically injected at a rate of 0.26 kg per 1000 kg of gas [48].

The aim of the research is to improve natural gas adsorption drying processes through the application of combined adsorbent bed layers.

2. RESEARCH OBJECTS AND METHODS.

The research objects included wet natural gas used in adsorption drying at "Shurtanneftegaz" LLC (Republic of Uzbekistan, Kashkadarya Region), as well as various adsorbents employed for gas drying, including silica gels, aluminum oxide, and zeolites.

2.1. Laboratory Unit for Natural Gas Adsorption Drying.

The method for determining the adsorption capacity of adsorbents and the degree of drying under dynamic conditions includes the following steps. An adsorbent sample is calcined in a muffle furnace at a temperature of 350°C for 4 hours. It is then cooled in a desiccator over a layer of zeolite and weighed. After that, the adsorbent is loaded into the adsorption unit.



Figure 4. Laboratory Unit for Adsorption Drying of Gases Manufactured by EKSIS

A laboratory setup for determining the adsorption capacity of adsorbents and the drying efficiency under dynamic conditions is shown in Figure 4 (Laboratory unit for gas adsorption drying manufactured by the "EKSIS" company).

The laboratory unit consists of an adsorber, mixer, droplet separator, and gas flow meter. A stream of wet gas is passed through the unit. To determine the moisture content of the dried gas, a coulometric moisture analyzer is installed. The experimental tests are terminated after the highest value of the gas dew point is recorded.

2.2. Gravimetric Method for Determining Moisture Content in Gas COMPOSITION.

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The gravimetric (mass-based) method for determining moisture content in gas is based on the adsorption of water vapor by certain substances. Such substances include calcium chloride, silica gel, sulfuric acid, phosphorus pentoxide, and others. When selecting one of these moisture absorbents, it is necessary to consider that some of them may absorb not only water vapor but also gaseous impurities such as SO_2, Cl_2, CO_2, and other components. This can affect the accuracy of the final results obtained [49, 50].

In the gravimetric method, a known volume of gas is passed through a series of adsorbers connected in sequence and filled with a moisture-absorbing material (Figure 5).

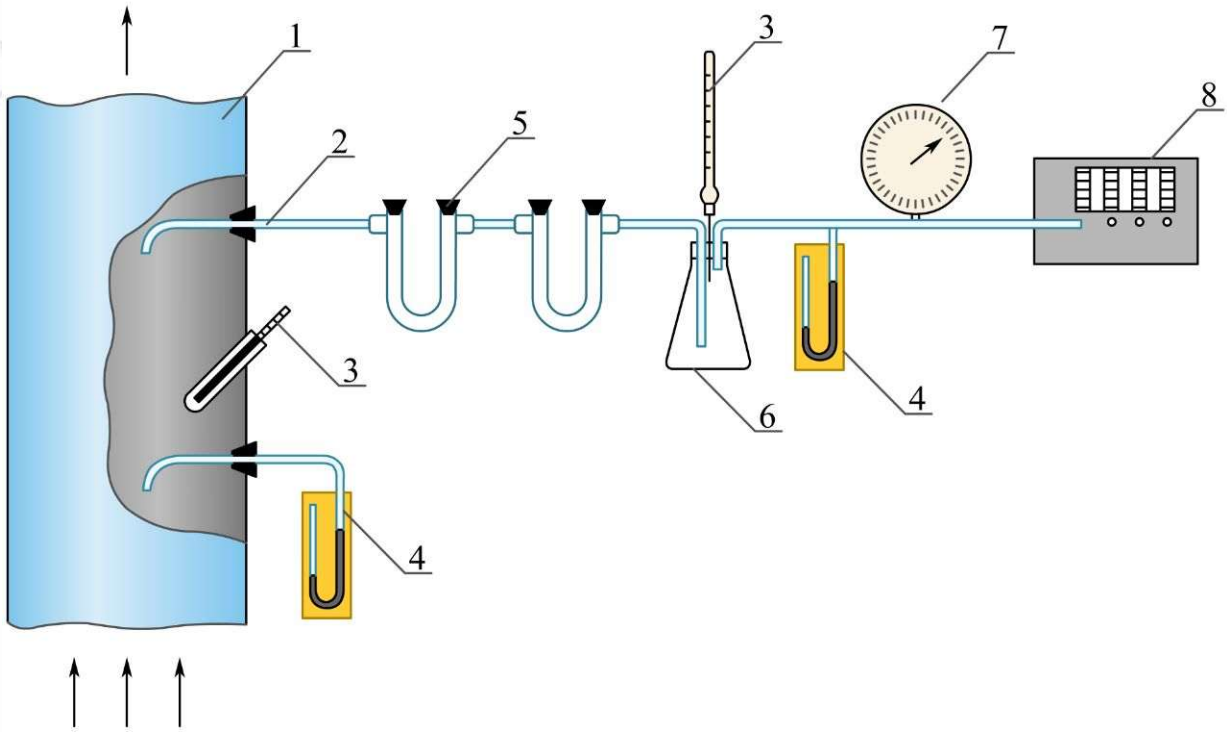


Figure 5. Schematic diagram for determining the moisture content of gas using the gravimetric method: *1 – gas line, 2 – sampling tube with filter, 3 – thermometer, 4 – manometer, 5 – U-shaped absorption tube, 6 – hydraulic barrier (installed only when using a liquid absorbent, such as sulfuric acid), 7 – gas meter, 8 – electric aspirator*

The tubes containing the absorbent are weighed on an analytical balance before the analysis (m_1) and after the analysis (m_2). Knowing the amount of absorbed moisture and the volume of gas passed through the system (V_G), the absolute moisture content of the gas is calculated using the following equation [51, 52, 53, 54]:

$$f'' = \frac{m_2 - m_1 * 1000}{\left(V_G\tau = \frac{273}{273 + t_G} \cdot \frac{B - R_P}{760}\right) + \left(\frac{m_2 - m_1}{0{,}804}\right)}$$

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where: *where: m_1 – is the mass of the adsorbent prior to water vapor adsorption, g; m_2 – is the mass of the adsorbent after water vapor adsorption, g; V_G – is the volume of gas passed through the adsorbent tube, L/min; τ – is the transit time of the gas sample under investigation through the adsorbent tube, min; t_G – is the temperature of the gas, measured after water vapor has been adsorbed, °C; R_P – is the pressure of the gas sample after water vapor has been adsorbed, mm Hg.*

During sampling, a decrease in the resistance of the solid absorbent filter must be avoided, as this indicates saturation with water vapor and will lead to erroneous results. Additionally, the gas sampling rate must be strictly controlled. The gas sample is taken at a rate of 0.5–1.0 L/min (sampling duration of 10–15 minutes). If the gas sample is taken at a rate lower than 0.5 L/min, the water vapor in the gas may condense in the sampling tube. If taken at a rate higher than specified, the hydraulic resistance in the system will increase, and the results will be inaccurate.

3. RESULTS AND ANALYSIS.

In the first stage of the research, the chemical composition and physicochemical properties of the natural gas processed at “Shurtanneftgaz” LLC, used as the object of study, are presented in Table 2.

Table 2

Chemical composition and physicochemical properties of natural gas processed at “Shurtanneftgaz” LLC

№	Physicochemical Properties of the Gas		Indicator
1	Chemical composition of natural gas, %	C_1	91,76
		C_2	5,79
		C_3	1,09
		n-C_4	0,16
		i-C_4	0,13
		n-C_5	0,05
		i-C_5	0,05
		$C_{6+\ high}$	0,07
		CO_2	0,05
		H_2S	0,01
		N_2	0,84
2	Density, kg/m^3		0,7301
3	Molecular Mass		17,880
4	Gross Calorific Value under normal conditions, kcal/m^3		9430,9

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5	Net Calorific Value under normal conditions, kcal/m^3	8505,3
6	Wobbe Index, kcal/m^3	10925,3
7	Moisture Content, ppm	745,5

3.1. Determining the dehydration level of natural gas using combination adsorbents.

It was determined that with the help of KSMG silica gel, it is possible to dehydrate gases corresponding to the summer period for cold and temperate climate regions. In turn, it is worth noting that, considering the lower water resistance and abrasion resistance of KA (3Å) zeolite compared to KSMG silica gel and K1 activated aluminum oxide, we studied the gas dehydration level by placing the aforementioned adsorbents in the adsorber in various combinations to increase the operational life of this zeolite and, furthermore, to improve the efficiency of the adsorption process.

In the next stage of our research, the natural gas dehydration processes in combined-layer adsorbent beds were investigated by sequentially placing the above-mentioned adsorbents in various ratios. The combination of adsorbents for natural gas dehydration is presented in Table 3.

Table 3

Combination of adsorbents for natural gas dehydration

№	Adsorbents	Names of Adsorbent Compositions	Ratio, %
1	K1 aluminum oxide: KA (3Å) zeolite	**(K1:KA)**	50:50
2	K1 aluminum oxide: KSMG silica gel	**(K1:KSMG)**	50:50
3	K1 aluminum oxide:NaA (3Å) zeolite	**(K1:NaA)**	50:50
4	K1 aluminum oxide:KSMG silica gel:KA (3Å) zeolite	**(K1:KSMG:KA-1)**	20:20:60
5	K1 aluminum oxide:KSMG silica gel: KA (3Å) zeolite	**(K1:KSMG:KA-2)**	30:30:40

The sequence for layering the adsorbents was selected based on their abrasion resistance and water stability indicators.

The adsorption process was conducted under experimental conditions to determine the adsorption capacity of the adsorbents. The results of using the K1:KA combined adsorbent layer for natural gas dehydration are shown in Figure 6.

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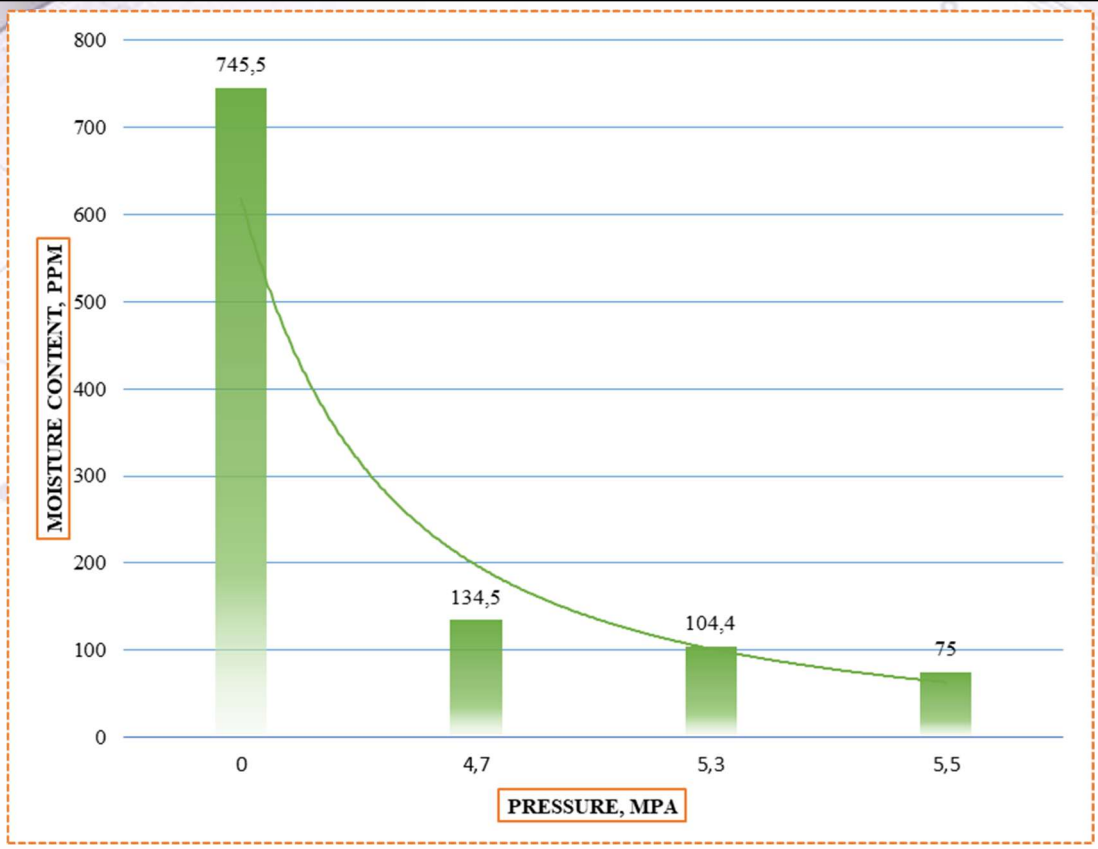


Figure 6. The degree of natural gas dehydration by the K1:KA combination adsorbent layer at a temperature of 28°C and various pressures

At a temperature of 28°C and a pressure of 5.5 MPa, the K1:KA combination adsorbent layer reduced the moisture content in natural gas to 75 ppm. This indicator is considered sufficient for temperate climate zones, particularly for the conditions in our country.

The results of natural gas dehydration using the K1:KSMG combination adsorbent layer are shown in Figure 7. The gas dehydration process in this combination adsorbent layer did not show particularly high results. However, it is possible to dehydrate natural gas with a dew point temperature near -10°C at a pressure of 3.92 MPa.

In our next study, the gas dehydration process was conducted in an adsorber with a K1:NaA combination adsorbent layer. The obtained results are presented in Figure 8.

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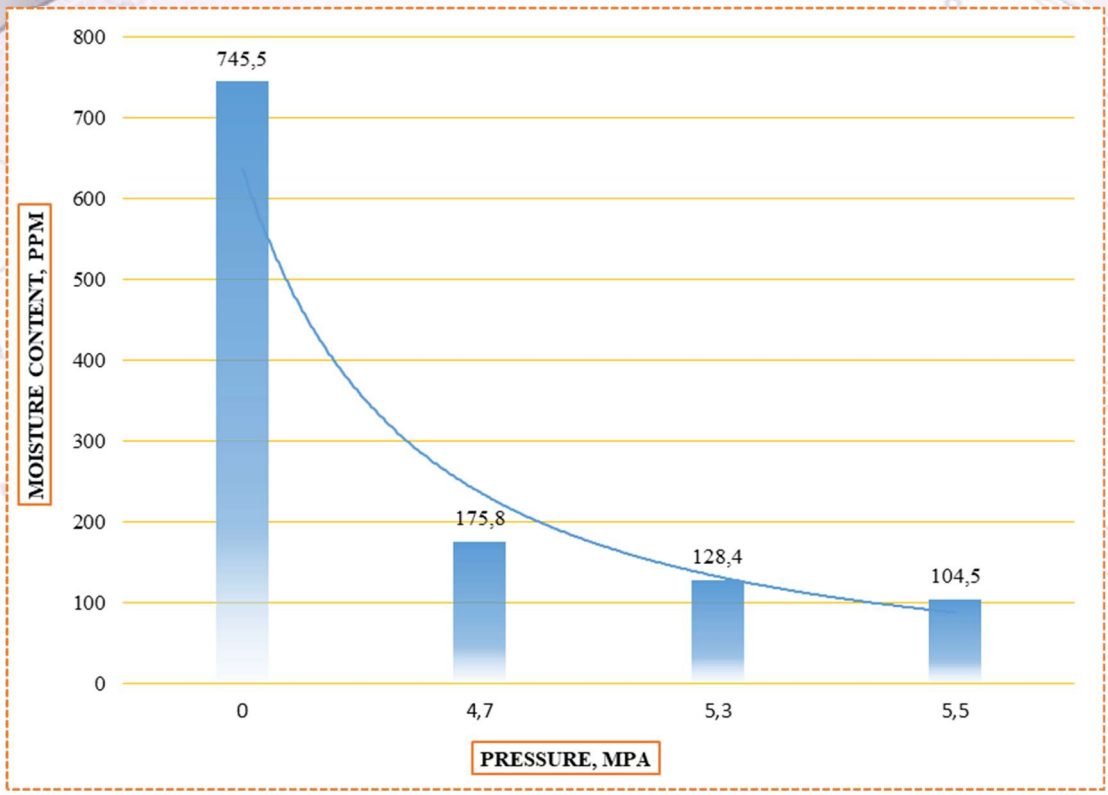


Figure 7. The degree of natural gas dehydration by the K1:KSMG combined adsorbent layer at 28°C and various pressures

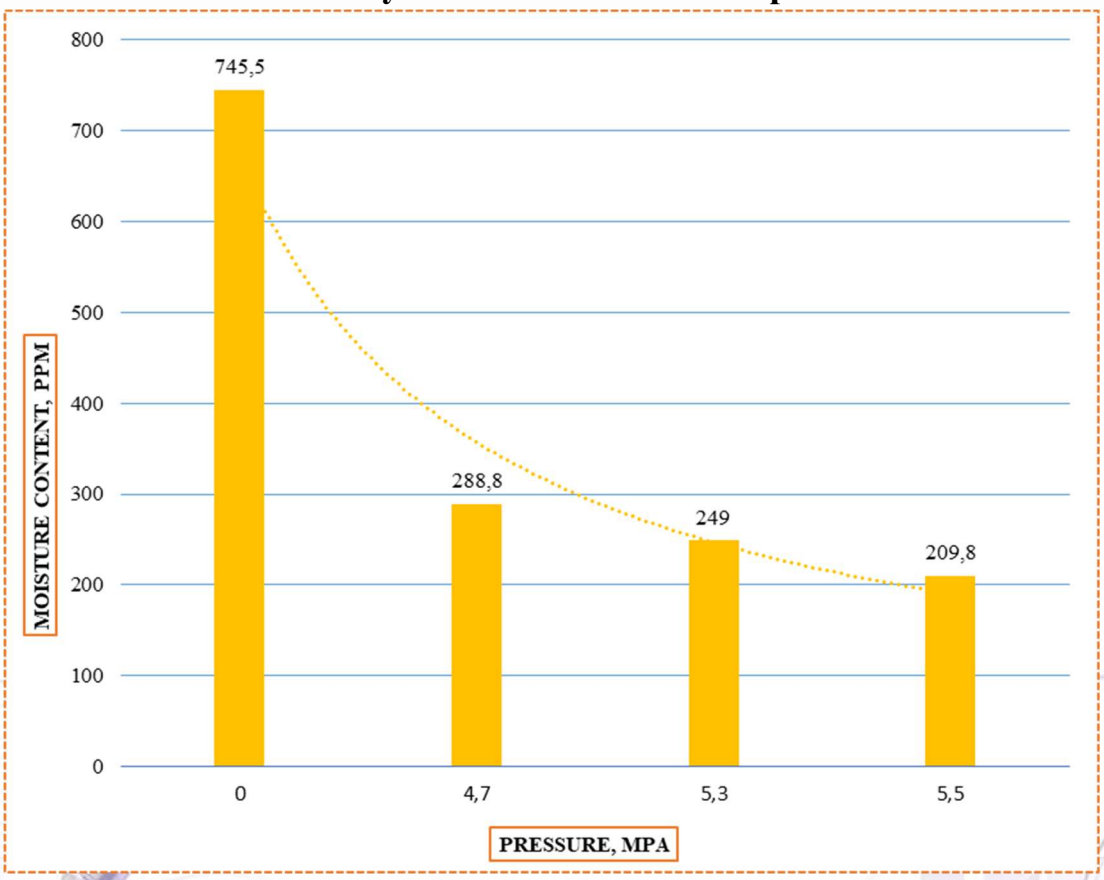


Figure 8. The degree of natural gas dehydration by the K1:NaA combination adsorbent layer at a temperature of 28°C and various pressures

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The degree of natural gas dehydration by the K1:NaA combination adsorbent layer at a temperature of 28°C and various pressures showed significantly lower results.

In the two types of combined-layer gas adsorption processes, the K1:KA adsorbent combination demonstrated a higher result. From the results of this study, we can see that the KA zeolite showed high results both individually and in combination. Therefore, an adsorption layer protected by K1 activated aluminum oxide, which showed the highest performance individually, was selected and tested in the gas dehydration process. This combination adsorbent layer was developed by varying the amount of KA zeolite.

The efficiency of the K1:KSMG:KA-1 combination adsorbent layer in natural gas dehydration is presented in Figure 9.

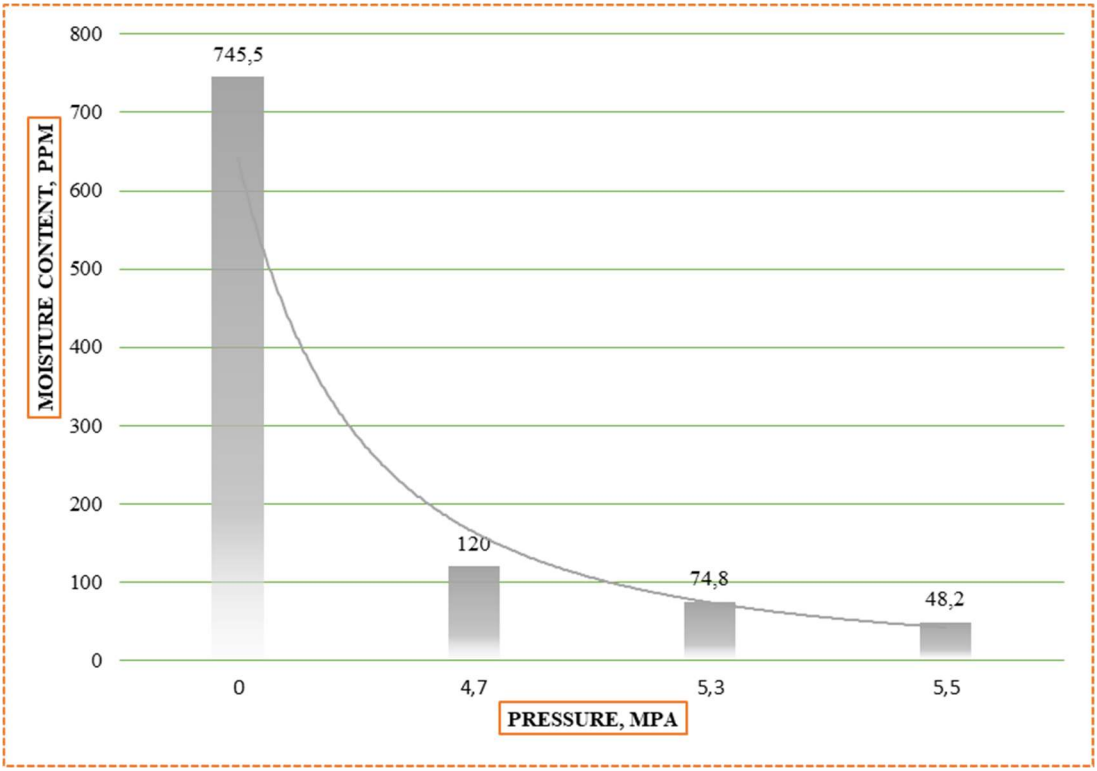


Figure 9. The degree of natural gas dehydration by the K1:KSMG:KA-1 combination adsorbent layer at 28°C and various pressures

The results showed that the K1:KSMG:KA-1 combination adsorbent layer reduces the moisture content in natural gas to 48.2 ppm at a temperature of 28°C and a pressure of 5.5 MPa. The efficiency of the K1:KSMG:KA-2 combination adsorbent layer in natural gas dehydration is shown in Figure 10.

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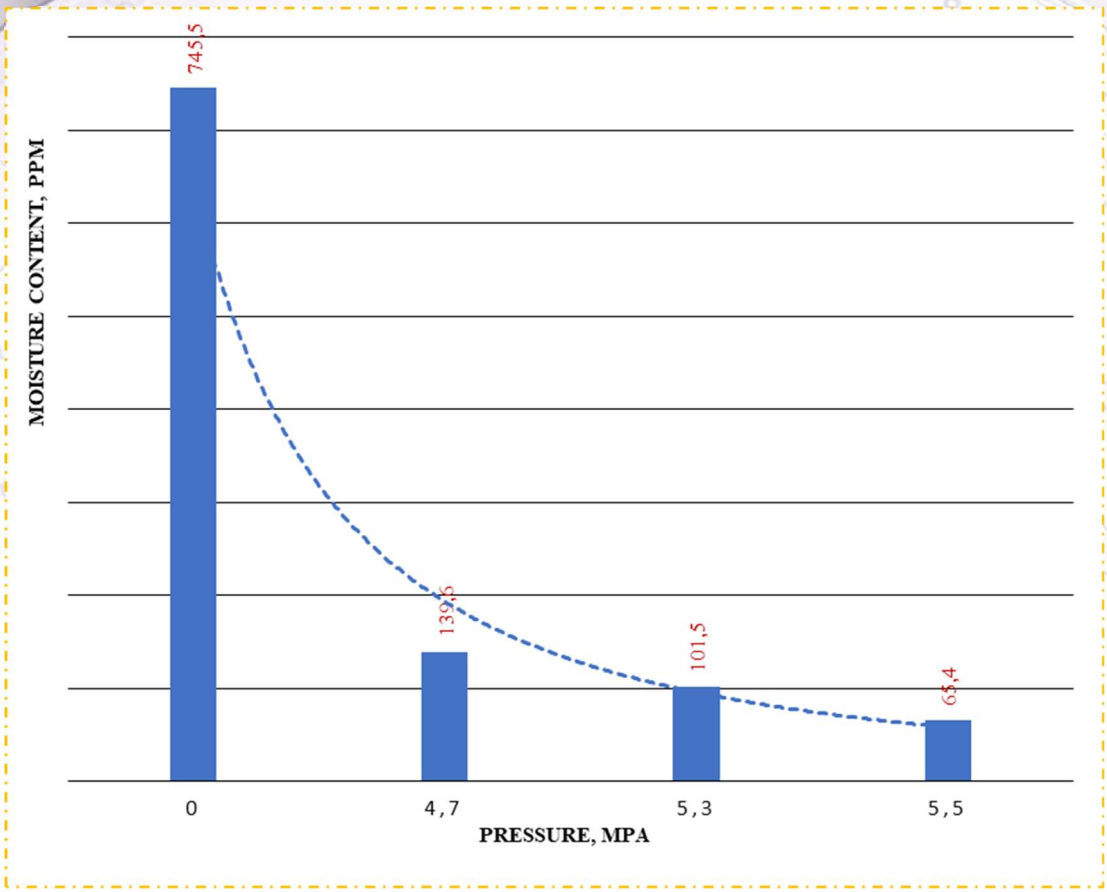


Figure 10. The degree of natural gas dehydration by the K1:KSMG:KA-2 combination adsorbent layer at a temperature of 28°C and various pressures

The results obtained showed that the K1:KSMG:KA-2 combination adsorbent layer reduces the moisture content in natural gas to 65.4 ppm at a temperature of 28°C and a pressure of 5.5 MPa.

In the gas dehydration combination consisting of three adsorbent layers, the superior result of K1:KSMG:KA-1 can be explained by its higher content of KA zeolite (60%).

Based on the conducted research, it is concluded that the K1:KSMG:KA-1 combination adsorbent layer and the individual KA (3Å) zeolite showed high results in dehydrating natural gas, and it is experimentally proven that they enable gas dehydration that meets both summer and winter requirements for all climatic conditions. In the next stage of our research, the adsorption cycle and regeneration conditions of this adsorbent and combination adsorbent layer were investigated.

Currently, at “Shurtanneftegaz” LLC, the adsorption cycle for the NaA zeolite used in gas dehydration is 6 hours, while the regeneration and cooling processes take 1.5 hours.

The adsorption process was conducted for 15 hours at a temperature of 28°C and a pressure of 3.923 MPa. The obtained results are presented in Figure 11.

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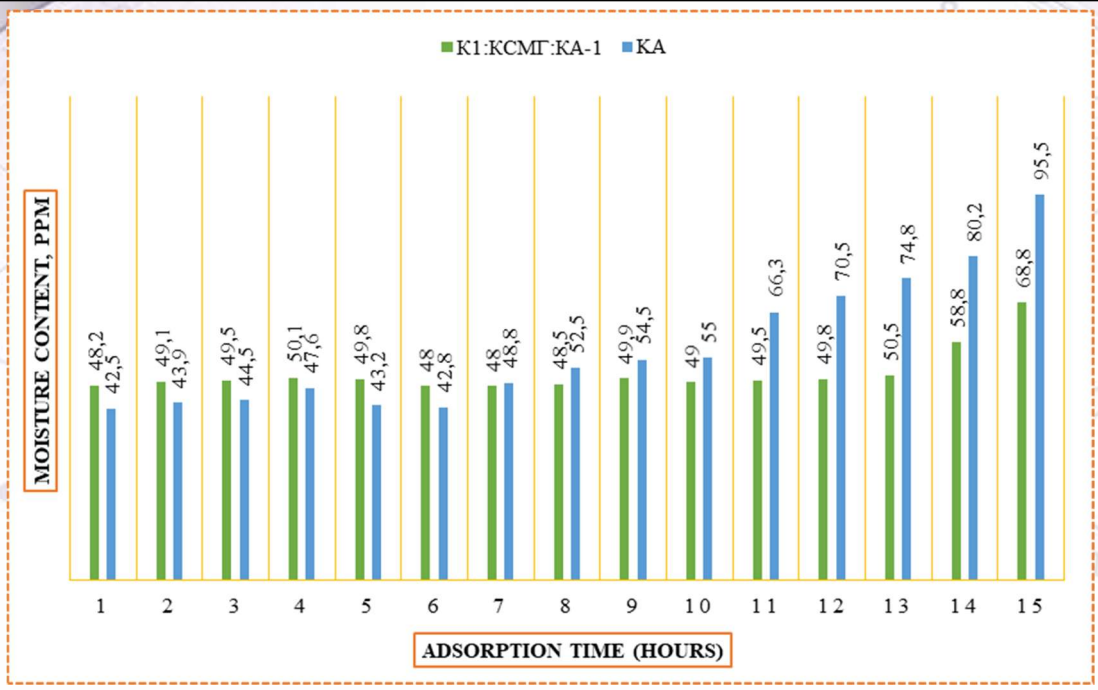


Figure 11. Adsorption duration of the K1:KSMG:KA-1 combination adsorbent layer and individual KA (3Å) zeolite during natural gas drying

The results of these experiments showed that the duration of adsorption activity for the K1:KSMG:KA-1 combination adsorbent layer was 12 hours, while that of the KA zeolite was 7 hours. This can be explained by the fact that in the K1:KSMG:KA-1 combination adsorbent layer, the K1 aluminum oxide partially absorbs various substances from the natural gas (mechanical particles, liquid hydrocarbons, etc.) and some moisture. This prevents the KSMG and KA components, which have a high capacity for water vapor absorption, from becoming saturated with these other substances. It can be inferred that the adsorption duration for the KA zeolite is significantly shorter because its pores become filled by absorbing several other substances along with water vapor.

3.2. Development of natural gas drying conditions and adsorber design for the K1:KSMG:KA-1 combination adsorbent layer.

The drying conditions for natural gas using the K1:KSMG:KA-1 combination adsorbent layer are presented in Table 4.

Table 4

Conditions for natural gas drying using the K1:KSMG:KA-1 combination adsorbent layer

№	Names of quantities	Unit of measure	Magnitude values		
			Min.	*Max.*	*Average*
1	**2**	**3**	**4**	**5**	**6**
Expenditure					

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1	Gas entering one block for purification	Thousand m^3/hour	100	500	400
2	Gas entering one adsorber for purification	Thousand m^3/hour	-	83	66
3	Purified gas used in zeolite regeneration and cooling	Thousand m^3/hour	30	60	45
4	Fuel gas supplied to the heating furnace	Thousand m^3/hour	100	630	580
5	Purified (commercial) gas	Thousand m^3/hour	90	450	360
Pressure					
6	Gas entering the purification process	MPa	5,5	5,7	5,5
7	Clean (commercial) gas	MPa	5,3	5,5	5,3
8	Regeneration and cooling gas	MPa	5,8	6,0	5,8
9	Pressure drop across one layer of the adsorber	MPa	0,65	0,65	0,65
Temperature					
10	Gas for purification	°C	28	28	28
11	Cooling gas	°C	25	25	25
Time					
12	Adsorption	Hour	12	12	12
13	Regeneration	Hour	1,5	2	1÷2
14	Cooling	Hour	1,5	2	1÷2

The parameters for these studies were determined based on the state standards presented in Chapter 2. The drying conditions for natural gas in the K1:KSMG:KA-1 combination adsorbent layer we are recommending are similar to those currently in use. However, the adsorption time for the K1:KSMG:KA-1 combination adsorbent layer is twice that of the NaA zeolite layer. This, in turn, allows for a twofold reduction in the frequency of adsorbent desorption, which consequently makes it possible to cut technological process costs by half.

At “Shurtanneftgaz” LLC, natural gas is dried using a single type of adsorbent, NaA. The structure of the adsorber used in this process is shown in Figure 12. To use the K1:KSMG:KA-1 combination adsorbent layer we have

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selected for natural gas applications, partial structural modifications to these adsorbers are required.

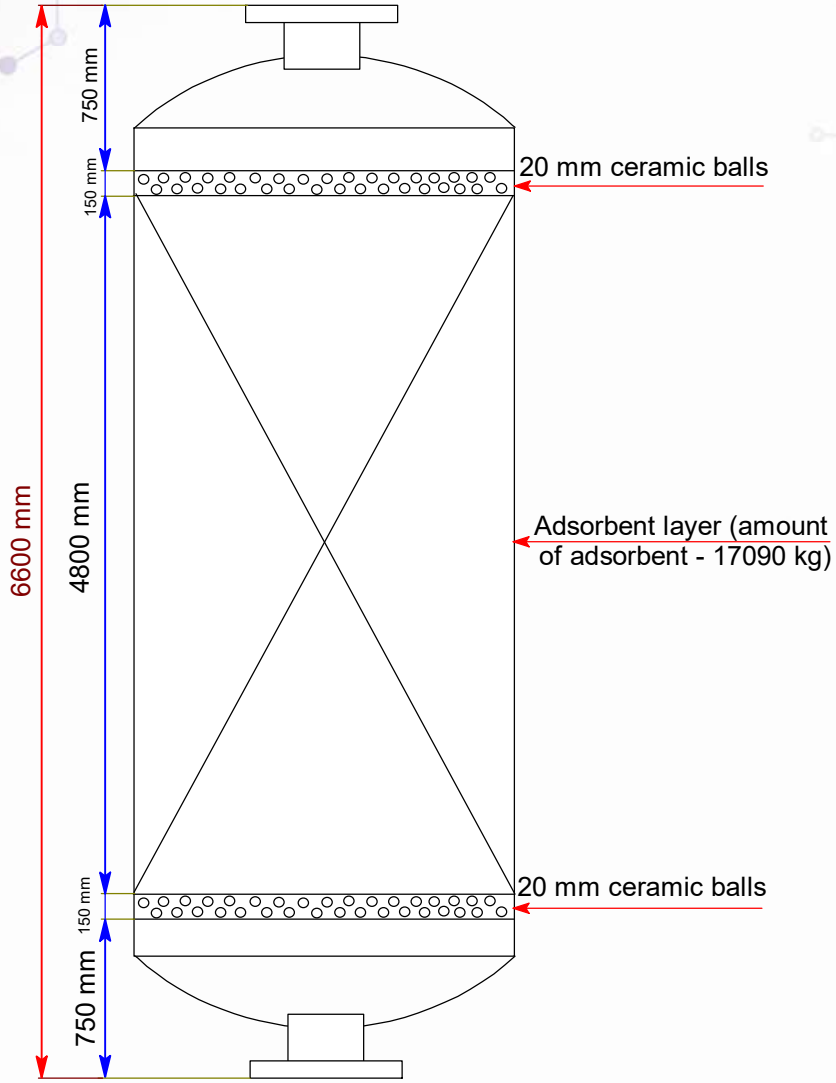


Figure 12. A general view of the adsorber used for natural gas dehydration at "Shurtanneftegaz" LLC

We, therefore, converted this single-layer adsorber into a three-layer design. Each layer was separated by a stainless steel mesh with 1x1 mm dimensions and 1 mm perforations. A general diagram of this adsorber is shown in Figure 13.

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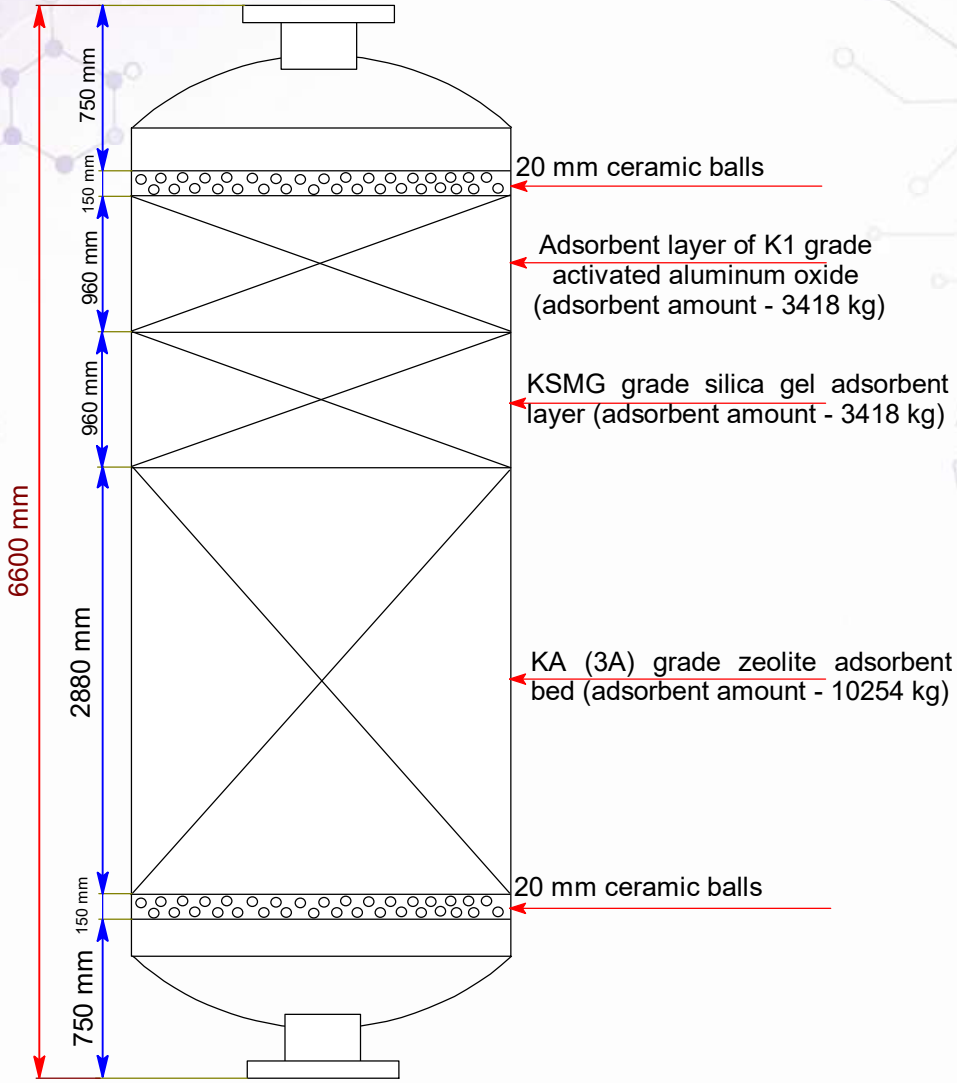


Figure 13. General view of the proposed adsorber

The physicochemical properties of the wet natural gas feedstock after adsorption dehydration at "Shurtanneftegaz" LLC using a K1:KSMG:KA-1 combination adsorbent layer are shown in Table 5.

Table 5

Physicochemical properties of the wet natural gas feedstock at "Shurtanneftegaz" LLC after adsorption dehydration

№	Physicochemical Properties of the Gas		Indicator
1	Chemical composition of natural gas, %	C_1	92,04
		C_2	6,00
		C_3	0,98
		n-C_4	0,12
		i-C_4	0,09
		n-C_5	0,04
		i-C_5	0,03

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		C_{6+} high	0,03
		CO_2	0,05
		H_2S	0,01
		N_2	0,61
2	Density, kg/m^3		0,7258
3	Molecular Mass		17,678
4	Gross Calorific Value under normal conditions, kcal/m^3		9435,4
5	Net Calorific Value under normal conditions, kcal/m^3		8512,1
6	Wobbe Index, kcal/m^3		10944,2
7	Moisture Content, ppm		48,2

As the results in the table above indicate, there is a partial decrease in the content of propane, butane, and liquid hydrocarbons in the dried natural gas. We can also observe that the reduction in the amount of C_{5+} hydrocarbons in the gas, along with the lowering of its dew point, has led to a slight increase in both its higher and lower heating values under normal conditions.

4. CONCLUSIONS.

1. Combination adsorbent layers K1:KA, K1:KSMG, K1:NaA, K1:KSMG:KA-1, and K1:KSMG:KA-2 were developed, and their natural gas dehydration levels were determined. It was demonstrated that the K1:KSMG:KA-1 combination adsorbent layer can reduce the water content in natural gas to 48.2 ppm at a temperature of 28°C and a pressure of 5.5 MPa.

2. The adsorption duration for the K1:KSMG:KA-1 combination adsorbent layer and the individual KA (3Å) zeolite in natural gas dehydration was determined. The research findings showed that the duration of adsorption activity was 12 hours for the K1:KSMG:KA-1 combination adsorbent layer, while it was 7 hours for the KA zeolite.

3. It was proven that by implementing the proposed combination adsorbent layer, the adsorption time can be extended from 6 to 12 hours, and the regeneration process can be reduced by up to two-fold.

4. Based on the results obtained, the operating conditions for applying the recommended K1:KSMG:KA-1 combination adsorbent layer for gas dehydration were developed, involving partial structural modifications to existing adsorbers.

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