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Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
НАУК РЕСПУБЛИКИ
КАЗАХСТАН
Satbayev University

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SECTIONING OF PETROLEUM GAS ADSORPTION DRYING

Abstract. An analysis of the operation of an adsorption plant for drying petroleum gas at the Kenlyk field was carried out. The adsorption process is characterized by versatility, which allows simultaneous drying and purification of gas from various components, as well as high efficiency. The organization of associated petroleum gas drying in adsorbers simplifies the gas treatment technology. This is evidenced by the absence of a significant amount of moisture, which forms blockage of pipelines with ice plugs after throttling of petroleum gas. The parameters of operation, advantages and disadvantages of the gas drying unit for associated petroleum gas at the Kenlyk field are determined. Based on the analysis of the operation of the adsorption drying unit, a three-section scheme of the oil gas adsorption drying unit is proposed. In this case, the non-working part of the adsorbent layer is reduced, respectively, the energy costs to overcome the hydraulic resistance of this layer are reduced. During adsorption through the thickness of the adsorbent layer, only the dynamic part of the adsorbent layer actively works, while the gas passes through the rest of the adsorbent layer (not the working part) unchanged. These processes occur both during adsorption and during regeneration of the adsorbent. The height of the section of the adsorption apparatus was determined, which ensures high drying rates during the entire period of operation of the adsorbent, also to prevent the formation of bypass channels and voids in the adsorber. To assess the economic feasibility of the proposed scheme, an approximate calculation of the cost of depreciation, operating, energy and capital costs of the existing and proposed adsorption plant was made. It is shown that the use of the proposed three-section plant is more economically feasible than the existing adsorption plant by 63.6%.

Key words: adsorption, petroleum gas, dehydration, gas velocity, plant.

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МҰНАЙ ГАЗЫН АДСОРБЦИЯЛЫҚ КЕПТІРУДІ СЕКЦИЯЛАУ

Аннотация. «Кеңлік» қазба орнының іліспе мұнай газын адсорбциялық кептіретін қондырғының жұмысы талданды. Адсорбциялық процесс әмбебап болып табылады, газды әртүрлі компоненттерден бір уақытта кептіру мен тазартуға болады, сонымен қатар жоғары тиімділікке жетуге мүмкіндік береді. Ілеспе мұнай газын адсорберлерде кептіруді ұйымдастыру газды өңдеу технологиясын жеңілдетеді. Бұл мұнай газын дроссельдеуден кейін құбырлардың мұз тығындарымен бітелуін қалыптастыратын ылғалдың айтарлықтай мөлшерінің болмауымен дәлелденеді. «Кеңлік» қазба орнының газ кептіру қондырғысының жұмыс параметрлері, артықшылықтары мен кемшіліктері анықталды. Адсорбциялық кептіру қондырғысының жұмысын талдау негізінде адсорбциялық кептірудің үш секциялық схемасы ұсынылған. Бұл кезде адсорбент қабатының жұмыс істемейтін қалыңдығы азаяды, сәйкесінше, осы қабаттың гидравликалық кедергісі төмендеп, энергия шығындары азаяды. Адсорбент қабатының қалыңдығы арқылы адсорбциялау кезінде адсорбент қабатының динамикалық бөлігі ғана белсенді жұмыс істейді, ал газ адсорбент қабатының қалған бөлігінен (жұмыс бөлігі емес) өзгеріссіз өтеді. Бұл процестер адсорбция кезінде де, адсорбенттің регенерациясында да жүреді. Адсорбентті барлық эксплуатациялау кезінде кептірудің жоғары көрсеткішін қамтамасыз ететін, сонымен қатар адсорберде байпастық арналар, кеуектер түзілуін болдырмайтын адсорбциялық аппарат секциясының биіктігі анықталды. Ұсынылған адсорбциялық схеманың экономикалық тиімділігін бағалау үшін оның амортизациялық, энергетикалық және капиталдық шығындары есептелінді. Ұсынылған үшсекциялы кептіру қондырғысының қолданыстағы адсорбциялық қондырғыдан 63,6% экономикалық тиімді екені дәлелденді.

Түйін сөздер: адсорбция, мұнай газ, кептіру, газ жылдамдығы, қондырғы.

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СЕКЦИОНИРОВАНИЕ АДСОРБЦИОННОЙ ОСУШКИ НЕФТЯНОГО ГАЗА

Аннотация. Выполнен анализ работы адсорбционной установки для осушки нефтяного газа месторождения «Кенлык». Адсорбционный процесс отличается универсальностью, что позволяет одновременную осушку и очистку газа от различных компонентов, а также высокой эффективностью. Организация осушки попутного нефтяного газа в адсорберах упрощает технологию подготовки газа. Этому свидетельствует отсутствие значительного количества влаги, образующие закупорку трубопроводов ледяными пробками после дросселирования нефтяного газа. Определены параметры работы, преимущества и недостатки узла осушки газа попутного нефтяного газа на месторождении Кенлык. На основе анализа работы узла адсорбционной осушки предложена трехсекционная схема узла адсорбционной осушки нефтяного газа. При этом нерабочая часть слоя адсорбента сокращается, соответственно уменьшаются затраты энергии на преодоление гидравлического сопротивления этого слоя. При адсорбции по толщине слоя адсорбента активно работает только динамическая часть слоя адорбента, а в остальной части (нерабочей части) адсорбента газ проходит без изменений. Эти процессы происходят как и при адсорбции, так и при регенерации адсорбента. Определена высота секции адсорбционного аппарата, обеспечивающей высокие показатели осушки в течение всего периода эксплуатации адсорбента, а также для предотвращения образования байпасных каналов и пустот в адсорбере. Для оценки экономической целесообразности предлагаемой схемы выполнен ориентировочный расчет стоимости амортизационных, эксплуатационных, энергетических и капитальных расходов существующей и предлагаемой адсорбционной установки. Показано, что использование предлагаемой трехсекционной установки экономически целесообразнее существующей адсорбционной установки на 63,6%.

Ключевые слова: адсорбция, нефтяной газ, осушка, скорость газа, установка.

Introduction. For adsorption drying of petroleum gas, solid adsorbents are used, which have a large surface area of phase contact due to capillary pores. In industry, activated alumina, florite, silica gel, bauxite, zeolites (molecular sieve), etc. are used as adsorbents (Liu K., et all, 2015: 853, Ralph T. Yang, 1997:632, Serpionova E.N., 1969: 416, Shumetskiy Yu.I., 2005: 164, Sunil Jayant Kulkarni, 2016: 16, Toth Jozsef, 2019:904).

The content of water vapor (moisture) in gas, in particular in petroleum gas, adversely affects the operation of process equipment for processing and transporting petroleum gas. Therefore, they are usually dried to a dew point temperature of 40^0C.

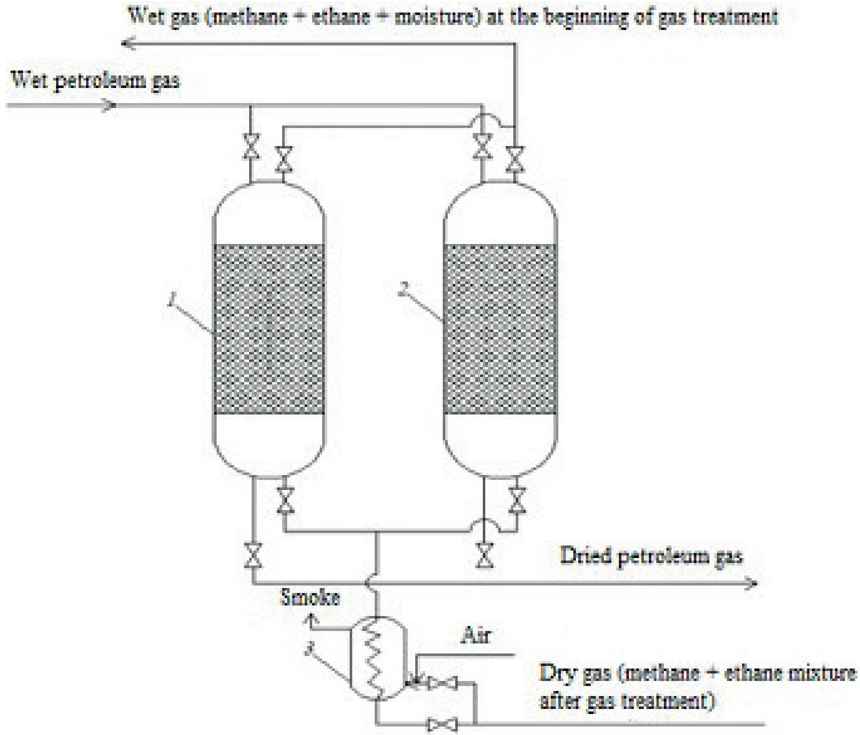
Adsorption drying of petroleum gas is the most effective method, and the efficiency of adsorption processes is determined, first of all, by the characteristics of the adsorbent used. Solid absorbers, including zeolites (molecular sieves), are the most widely used for drying petroleum gas.

Research materials and methods. Adsorption processes for drying petroleum gases are carried out in batch plant. It contains two adsorbers filled with adsorbent. These adsorbers work alternately, i.e. after saturation of the adsorbent with water vapor, the first adsorber switches to the stage of desorption (regeneration). And the second adsorber switches from the regeneration stage to the adsorption stage. At stage of regeneration, the adsorber goes through periods of increasing and decreasing the temperature of the adsorbent, its replacement, etc. (Chaczykowski M., 2011: 2219, Crespo D., Qi.G., 2008: 1238, Beisembetov I.K., 2020:6, Zholtayev G., 2018:29, Bogdanov R.M., 2014).

Schematic diagram of the dehydration of oil gas from the Kenlyk field is shown in Figure 1 (Technological regulations, 2014:22).

The adsorption method is used to dry associated petroleum gas at the Kenlyk field. Synthetic zeolite (molecular sieve) is used as an adsorbent. The gas treatment plant includes 2 adsorbers that work alternately. When one adsorber dries the petroleum gas, the other regenerates the adsorbent. The existing scheme for drying petroleum gas is shown in Figure 1.

Wet petroleum gas enters the first adsorber 1 where it passes from top to bottom through the adsorbent (zeolite) bed. The adsorbent (zeolite) absorbs water vapor and the dried gas is removed from the apparatus. The process of drying the gas is carried out within 10÷12 hours. Thereafter, the wet oil gas is directed through the second adsorber 2, and the first adsorber is switched off and connected to the regeneration line. To do this, dry gas is passed through the coil furnace 3 (part of the methane + ethane mixture obtained after the preparation of the petroleum gas). This gas in the furnace is heated to 180-200^0C and sent to a regenerated adsorber, where it removes moisture from the adsorbent (zeolite). This wet gas is then mixed with the feed gas and fed back to the gas treatment unit by a booster compressor.



1,2 - adsorbers, 3 - coil furnace for heating dry gas
Figure 1. Existing oil gas dehydration scheme

Such organization of associated petroleum gas drying in adsorbers simplifies the gas treatment technology. This is evidenced by the absence of a significant amount of moisture, which forms blockage of pipelines with ice plugs after throttling of petroleum gas.

However, the existing scheme for drying petroleum gas has disadvantages. This is the return of wet gas after regeneration back to the gas treatment plant, which complicates the operating modes of the plant. The absence of a cooling unit for the regenerated gas to extract moisture from it. The adsorbent is loaded from above, lowering under the action of gravity, which can lead to significant mechanical damage, and the adsorbent, being crushed, clogs individual sections of the adsorbent layer (Aerov M.E., 1979: 176, Orymbetov T.E., 2021a:295, Orymbetov T.E., 2021b:204).

The adsorbent used for drying petroleum gas has full activity (capacity), for example, NaA-U zeolite can absorb water vapor in an amount of ~120 mg/cm^3 (Shumetskiy Yu.I., 2005:164, Serpionova E.N., 1969:416, Sunil Jayant Kulkarni, 2016:16). In this case, the entire free space of the adsorbent granules is balanced to the maximum filled with moisture.

The purpose of the study: development of a sectional diagram of an adsorption drying unit for petroleum gas, to reduce the non-working part of the adsorbent layer, reduce energy costs to overcome the hydraulic resistance of this layer and assess the economic feasibility.

Results and discussion. Under adsorption conditions, mass transfer region is formed in the adsorbent layer, which ensures the absorption of water vapor from the gas flow. In this case, concentration of water vapor in the gas flow changes from initial concentration Cн to the required Ck (figure 2).

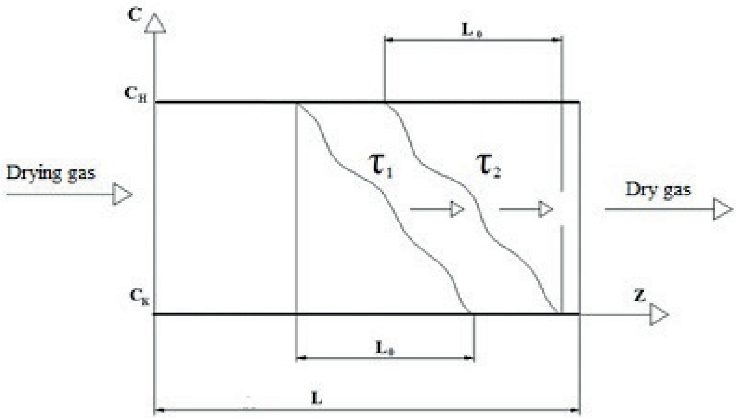


Figure 2. Graph of changes in the concentration of water vapor in adsorbent layer

Such change in the concentration of water vapor occurs along thickness of the adsorbent layer at distance L_0. If the thickness of the adsorbent layer L is less than distance $L_0 > L$, then the required final water vapor concentration C_k in the gas flow will not be reached. Usually, under real conditions, adsorption assumes that $L >> L_0$. Under these conditions, as adsorbent absorbs water vapor, mass transfer region (dynamic part of the mass transfer) moves in the adsorbent layer in the direction of the gas flow (figure 2).

Thus, during adsorption through the thickness of the adsorbent layer, only the dynamic part of the adsorbent layer L_0 actively works, and the gas passes through the rest of the (not working part) of the adsorbent without changes.

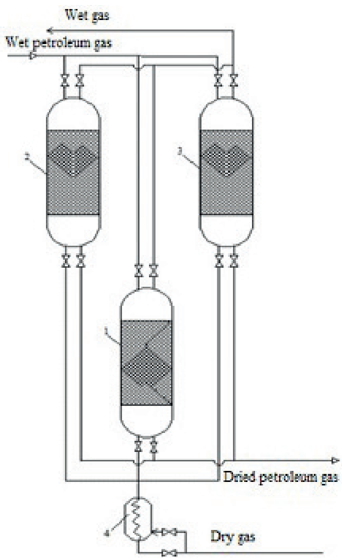
These processes occur both during adsorption and during regeneration of the adsorbent. When gas passes through non-working part of the adsorbent, useful energy is also expended to overcome the hydraulic resistance of the layer of the non-working part. Industrial adsorbers are designed for 1012 hours of operation during adsorption, while the second adsorber is at the stage of regeneration of the adsorbent and its cooling. Equipment for regeneration of the adsorbent operate cyclically, respectively, inefficiently.

To eliminate these shortcomings in the operation of the adsorption plant, sectioning of the adsorber is proposed.

The most effective, in our opinion, is a three-section adsorption plant, in which one adsorber of the existing plant is divided into 3 sections. And these sections work alternately in cycle: adsorption - regeneration - cooling (figure 3).

In this case, non-working part of the adsorbent layer is reduced, respectively, energy costs to overcome the hydraulic resistance of this layer are reduced. The proposed three-section scheme works as follows. The dried gas enters the adsorber section 1, where it is dried with an adsorbent for 4 hours, then it is taken out for further technological processing. After this time, the dried gas is supplied to the second section of the adsorber for 4 hours, and the first section of the adsorber switches to regeneration. After the second 4 hour time, the dried gas is supplied to the 3rd section of the adsorber, and the second one switches to regeneration and the first section switches to cooling. In the future, cycle is repeated.

In the proposed three-section adsorption plant, gas is dried continuously, but in adsorbers of low height. This makes it possible to reduce the energy costs for pumping dried gas both during adsorption and regeneration, and organize the continuous operation of the entire gas drying process.



1,2,3 - adsorbers; 4 - coil furnace for heating dry gas.
Figure 3. Scheme of 3-section adsorption plant for drying petroleum gas

To assess the economic feasibility of the proposed scheme, an approximate calculation of the cost of depreciation, operating, energy and capital costs of the existing and proposed adsorption plant was made.

In the existing adsorption plant, there are 2 adsorbers with a diameter d = 1.219 m, zeolite layer height H_1 = 2x8 m, gas flow Q = 13 000 nm^3/h, gas density $_н$ = 1.2 kg/m^3, molar mass M = 28.5 kg/kmol, gas pressure P = 6 MPa, gas temperature t = 40 ^0C (Shumetskiy Yu.I., 2005:164).

Determine amount of water absorbed in one section of the adsorption drying of petroleum gas in 4 hours (taking into account 10% moisture reserve) (Technological regulations, 2014:22)

$$G_в = 1.1 \cdot \frac{C_н}{1000} Q \cdot \tau_{ads} = 1.1 \frac{1.2}{1000} 13000 \cdot 4 = 68.64 \text{ kg}$$

For Na-U zeolite, we take a dynamic water vapor capacity of 10 g/100 g of adsorbent. The actual capacity of the zeolite in the initial period of its operation is much higher and amounts to ~ 16g/100 g of adsorbent. However, as operation progresses, due to the influence of various negative factors, capacity of the adsorbent decreases. The moisture capacity of the zeolite after 3-4 years of operation will approach the accepted capacity.

The volume of the required adsorbent for drying petroleum gas.

$$V_a = \frac{G_в}{\alpha_в \cdot \rho_a} = \frac{68.64 \cdot 100}{10 \cdot 800} = 0.86 \text{ m}^3$$

The internal diameter of the existing adsorber d=1.219 m, then the required height of the adsorbent layer

$$H = \frac{V_a}{0.785 \cdot d^2} = \frac{0.86}{0.785 \cdot 1.219^2} = 0.74 \text{ m}$$

To ensure the drying performance during the entire period of operation of the adsorbent, also to prevent the formation of bypass channels and voids in adsorber, height of the sections of adsorption apparatus is assumed to be H = 3 m.

In three-section adsorption plant, there are 3 adsorbers with diameter of d = 1.219 m, height of the zeolite layer H_2 = 3x3 m. The rest of the parameters are same as for the existing plant.

Let's accept, that cost of depreciation deductions for 1 m of length and 1 m of adsorber diameter Ca =2600·c_{el} t per year; cost of repair (operation) per 1 m of length and 1 m of adsorber diameter Cp = 400·c_{el} t per year; cost of the production area of the installation C_{pl} = 3000·c_{el} t per year, c_{el} - cost of electricity.

Gas velocity of adsorber cross section

$$w = \frac{Q \cdot \rho_н}{0.785 \cdot d^2 \cdot \rho_g} = \frac{13000 \cdot 1,2}{3600 \cdot 0.785 \cdot 1.219^2 \cdot 66} = 0.056 \text{ m/s}$$

where $\rho_g = \frac{P}{RT} = \frac{600000}{292\cdot313} = 66$ kg/m³ – dry gas density

The hydraulic resistance of the adsorbent layer is determined by Ergan formula [Ralph T. Yang, 1997:632]

$$\Delta P = H\left[150\frac{(1-\varepsilon)^2}{\varepsilon^3}\cdot\frac{\mu\omega}{d^2} + 1.75\frac{1-\varepsilon}{\varepsilon^3}\cdot\frac{\rho u^2}{d}\right] =$$

$$= H\left[150\frac{(1-0.375)^2}{0.375^3}\cdot\frac{17\cdot10^{-6}\cdot0.056}{1.219^2} + 1.75\frac{1-0.375}{0.375^3}\cdot\frac{66\cdot0.056^2}{1.219}\right] =$$

$$= H[4.746\cdot10^{-6}\cdot150 + 3.52] = 3.53H$$

Then the cost of spending for the existing installation

a) depreciation charges per year

$A_1 = H_1\cdot d\cdot C_a = 16\cdot1.219 \cdot 2600\ c_{el} = 50710{,}4\cdot c_{el}$.

b) cost of repair (operation) per year

$R_1 = H_1\cdot d\cdot C_p = 16\cdot1.219 \cdot 400\ c_{эл} = 7801.6\cdot c_{el}$.

c) production space cost

$P_1 = a_1\cdot b_1\cdot C_{пл} = 2\cdot3 \cdot 3000\ c_{el} = 18000\cdot c_{el}$,

where $a_1\cdot b_1 = 2x3 = 6$ м² – area occupied by existing installation.

d) energy cost for pumping gas

$$E_1 = \theta\cdot z\frac{Q\cdot\rho_g}{3600\cdot\rho_н}\cdot\frac{\Delta P}{1000\cdot0{,}5} = \frac{13000\cdot66\cdot3.53\cdot16}{3600\cdot12\cdot1000\cdot0.5}330\cdot40\cdot c_{el}$$
$$= 296142\cdot c_{el}\ \bar{t}.$$

Total costs for an existing adsorption plant

$C_1 = A_1 + R_1 + P_1 + E_1 = 50710.4\cdot c_{el} + 7801.6\cdot c_{el} + 18000\cdot c_{el} + 296142.3\cdot c_{el} = 372654.3\cdot c_{el}$ per year

Cost of the proposed three-section adsorption plant

a) depreciation charges per year

$A_2 = H_2\cdot d\cdot C_a = 9 \cdot 1.219 \cdot 2600\ c_{el} = 28524.6\cdot c_{el}$

b) cost of repair (operation) per year

$R_2 = H_2\cdot d\cdot C_p = 9 \cdot 1.219 \cdot 400\ c_{el} = 4388.4\cdot c_{el}$

c) production space cost

$P_2 = a_2\cdot в_2\cdot C_{pl} = 3\cdot4\cdot3000\ c_{el} = 36000\cdot c_{el}$,

where $a_2 \cdot b_2$ = 3x4 = 6 м^2 – area occupied by proposed installation.
d) energy cost for pumping gas

$$E = \theta \cdot z \frac{Q \cdot \rho_г}{3600 \cdot \rho_н} \cdot \frac{\Delta P}{1000 \cdot \eta} = \frac{1300 \cdot 66 \cdot 3{,}53 \cdot 3}{3600 \cdot 1{,}2 \cdot 1000 \cdot 0{,}5} 330 \cdot 48 \cdot c_{el} = 66632.28 \cdot c_{el}\ \bar{t}.$$

The total cost of expenses for proposed three-section adsorption plant
$C_2 = A_2 + R_2 + P_2 + E_2$ = (28524.6 + 4388.4 + 36000 + 66632.28)$\cdot c_{el}$= 1335545.3 $\cdot c_{el}$ per year.

Thus, use of the proposed three-section plant is more economically feasible than the existing adsorption plant on

$$\frac{C_1 - C_2}{C_1} 100 = \frac{(372654.3 - 135545.3) \cdot c_{el}}{372654.3 \cdot c_{el}} 100 = 63.6\%.$$

Conclusion. Thus, height of the section of adsorption apparatus was determined, which ensures high drying rates during entire period of operation of the adsorbent, also to prevent formation of bypass channels and voids in adsorber. To assess economic feasibility of the proposed scheme, approximate calculation of the cost of depreciation, operating, energy and capital costs of the existing and proposed adsorption plant was made. It shown, that use of the proposed three-section plant is more economically feasible than existing adsorption plant by 63.6%.

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