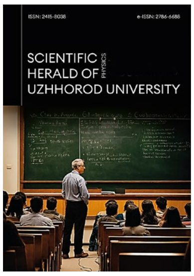
Scientific Herald of Uzhhorod University
Series "Physics"

Journal homepage: https://physics.uz.ua/en
Issue 55, 1–13
Received: 05.01.2024. Revised: 20.02.2024. Accepted: 12.03.2024



DOI: 10.54919/physics/55.2024.0ohj1

Optimization of amine gas purification technology from acidic components

Gulsim Muratova*
Master of Science
Kazakh-British Technical University
050000, 59 Tole bi Str., Almaty, Republic of Kazakhstan
https://orcid.org/0009-0009-7506-5531

Mikhail Tarabrin
Master of Science
University of Aberdeen
AB24 3FX, King's College, Aberdeen, United Kingdom
https://orcid.org/0000-0002-1419-530X

Abstract

Relevance. The relevance of investigating the processes of amine gas purification is manifested in the constant need to improve this technology to effectively reduce emissions of harmful substances into the atmosphere and in the search for more efficient, energy-saving and environmentally sustainable methods of cleaning gas streams.

Purpose. The purpose of this study is to analyze the effectiveness of existing methods of amine gas purification from acidic components to determine the most optimal and effective approach to ensure a high degree of purity of the purified gas.

Methodology. To achieve this goal, a statistical method, a comparative method, and analysis were used.

Results. As a result of the study, a detailed assessment of the key problems and disadvantages associated with the amine purification process was carried out. As part of this, the main factors affecting the effectiveness of the existing gas purification technology were identified. Among the proposed solutions, the importance of careful selection of the optimal composition of the alkanolamine mixture was identified. This important discovery highlighted the importance of the composition to ensure that the finished gas product meets quality standards. It is also an important step to maintain optimal conditions of the technological regime, which contributes to the more efficient operation of gas purification systems.

Conclusions. All the suggestions and improvements developed during the research have significant practical applications. Their implementation can reduce energy costs and increase the efficiency of gas purification from acidic components, which allows enterprises to introduce more efficient methods of gas purification and improve production quality.

Keywords: alkanolamines; foaming; absorbent; reagents; filtration; efficiency improvement.

Suggested Citation:
Muratova G, Tarabrin M. Optimization of amine gas purification technology from acidic compinents. *Sci Herald Uzhhorod Univ Ser Phys.* 2024;(55):1–13. DOI: 10.54919/physics/55.2024.0ohj1

*Corresponding author

Introduction

Purification of natural gases from acidic impurities is a key stage of their preparation before the processing. This stage is necessary to create high-quality gas ready for use in various industries. An important feature is that during the purification process, not only commercial gas is formed, but also acid gases, which can serve as raw materials for the production of chemical compounds, including sulphur. Alkanolamines play a significant role in the processes of purification of gas mixtures from acidic components. Their low viscosity ensures effective mixing with gas streams, which contributes to the uniform and complete removal of hydrogen sulphide (H_2S) and carbon dioxide (CO_2) [1-3]. Alkanolamines are adaptable to a wide range of pressures, which allows them to be used in various production conditions while maintaining a high degree of efficiency, which optimizes the gas purification process. However, despite its widespread use in the purification of gas mixtures from acidic components, the technology of absorption by alkanolamines faces a number of significant disadvantages. These problems include high energy consumption for amine regeneration, destruction of amines in the process, and potential contamination with various impurities and foaming during absorption [4; 5]. The use of amine purification raises a number of problems that require in-depth research and the search for effective ways to solve them. Among these tasks, the choice of absorption parameters is highlighted, and ensuring the optimal composition of acid gases. Equally important tasks are the disposal of exhausted amine solutions, the development of an energy-efficient amine regeneration process, the use of effective defoamers and anti-foaming agents, and many other tasks that require attention and further study.

Research conducted by N.S. Ivanov *et al.* [6] showed that alkanolamines play a significant role in the process of gas purification from acidic components. Their ability to form stable compounds with acid gases allows for effective purification from harmful impurities such as H_2S and CO_2. Due to their chemical properties and reactivity, alkanolamines are important in gas purification technologies and ensure high quality of the final product. A.K. Akurpekova *et al.* [7] confirmed the effectiveness of the use of alkanolamines in gas purification procedures, emphasizing their role in optimizing the processes of separating H_2S and CO_2 from natural gas. Studies have highlighted that the benefits of using these chemical compounds not only increase the efficiency of purification, but also contribute to minimising environmental impacts by reducing the overall consumption of reagents and process waste.

T. Daminov *et al.* [8] note that examples of amines such as diethanolamine (DEA) and methyldiethanolamine (MDEA) are particularly effective at absorbing CO_2 from gas streams. The comparison of the kinetics and thermodynamics of absorption processes were verified, which helped to fine-tune the purification processes to specific requirements. It was also emphasized that the use of MDEA provides higher selectivity in the separation of CO_2, while DEA is more effective in conditions of high concentrations of acid gases. A.E. Kemelzhanova *et al.* [9] drew attention to the problems that may arise when using alkanolamines in gas purification processes. One of these aspects is the corrosion of equipment, which can be caused by acidic compounds formed during the reactions of alkanolamines with acid gases. Attention was focused on the importance of developing improved methods for the neutralization and regeneration of alkanolamines to increase their effectiveness and reduce the negative impact on infrastructure.

F.R. Ismagilov *et al.* [10] focused on the stability of alkanolamines when used on an industrial scale for gas purification. It was noted the need to search for new, more stable alkanolamine formulas that would be able to maintain their performance characteristics for a long time, thereby minimising the frequency of replacement and renewal of cleaning solutions, which has a positive effect on the economic efficiency of cleaning procedures.

Since the technology of gas purification with amines has a number of disadvantages that were not considered in the above papers. The purpose of this study was to analyze the effectiveness of current purification methods and develop a new approach to the process of amine purification. As part of this study, various amine compositions were analyzed. Based on these data, recommendations were developed to optimize the gas purification process to reduce negative aspects and increase the efficiency of the entire process.

Materials and Methods

This study was carried out at the Kashagan field, UKPNiG Zapadny Eskene, Bolashak plant (Atyrau region, Kazakhstan). The comparative method, statistical method, and analysis were applied in the framework of research. These methods were used to process and interpret the data, which helped to better understand the nature of the difficulties encountered and formulate the most effective measures to eliminate them. These methods helped to identify factors that significantly affect the quality and efficiency of the process, which, in turn, contributes to the development of more accurate and targeted methods for solving them.

The statistical method was used to evaluate a set of experimental data obtained during various laboratory and field tests. With its help, correlations and patterns in the behavior of various compositions of alkanolamines were revealed. This method also allowed identifying key parameters that affect the efficiency of gas purification from acidic impurities. This helped to identify the optimal combinations of alkanolamines and the most important factors affecting the purification process. The results obtained allow optimizing production conditions to improve the process of gas purification from acidic components.

The comparative method determined that different combinations of alkanolamines have different efficiencies in the absorption of H_2S, ensuring the removal of this component from gas streams. It stressed the importance of choosing the optimal composition of alkanolamines to increase the efficiency of the gas purification process from H_2S. This approach allowed more effective management of the content of harmful components in the treated gases. A comparative assessment of the effect of temperature and pressure on the decomposition of amines highlighted the importance of controlling these parameters in the gas purification process.

In the context of the use of defoamers, a comparative analysis of the proposals helped to provide practical recommendations on the optimal use of various additives for foam control. This can help to ensure more efficient process management and minimize the negative phenomena associated with the appearance of foam during the gas purification process. A detailed analysis, in turn, revealed useful information about the processes of amine gas purification. Using the analysis, a thorough study was conducted of the proposed improvement in the amine purification process associated with the replacement of diethanolamine with its mixture with methyldiethanolamine. This technical change was subjected to an in-depth analysis based on a comprehensive study of the effect of mixing different types of amines on the quality of the gas product.

The analysis also revealed that the replacement of diethanolamine with a combined solution with methyldiethanolamine leads to an increase in the concentration of H_2S in acid gases, which plays a key role in effective purification with amines. During the analysis, it was pointed out the importance of this improvement in ensuring the required CO_2 content in the final gas product. The proposed improvement is aimed at ensuring a balance between the content of CO_2 and H_2S in gases, which is important for achieving high efficiency and precision control of the gas purification process. The analysis highlighted these technical points and emphasized their importance for ensuring that the gas product meets strict standards and requirements. In addition, the analysis was used to identify the causes of foam in solutions and evaluate the effectiveness of various defoamers. Different types of reagents were investigated to find the most suitable under conditions specific to specific amine gas purification plants. This helped to determine the optimal mixtures and reagents to reduce foaming, providing a more stable gas purification process.

Thus, statistical and comparative methods, and detailed analysis, provided objective and accurate data, based on which recommendations for optimizing cleaning operations were developed. The results obtained can serve as a basis for introducing changes in the process of amine gas purification, which will contribute to improving its efficiency and reliability, reduce energy consumption, and improve the quality of the final product.

Results

When using acid gases as a starting material for sulphur production, there are several key factors affecting the process. One of them is the concentration of H_2S in these gases, since it plays a decisive role in the creation of the final product. At the same time, the increased CO_2 content in acid gases causes problems in combustion in thermal stage furnaces. This leads to a deterioration of the combustion process and a decrease in the conversion of reacting components, which affects the final productivity of production. Optimizing the H_2S content in acid gases during natural gas purification is becoming a critical task. To achieve this goal, it is necessary to use specialized absorbents capable of selectively interacting with H_2S, which will increase the concentration of H_2S. This process is not only aimed at increasing the efficiency of subsequent sulphur production, but also plays an important role in ensuring the optimal functioning of production plants and maintaining a high level of productivity when using acid gases for industrial purposes [11-13].

Sometimes, when using DEA as an absorbent, there is a problem of its non-selectivity with respect to H_2S. To improve this situation, tertiary amines can be used, for example, MDEA, which has selectivity to H_2S and practically does not interact with CO_2. However, such a replacement may lead to an increase in the CO_2 content in the commercial gas, which may not meet the quality requirements. To increase the selectivity to H_2S, it is possible to use a mixture of DEA and MDEA, which is selective for H_2S. However, to avoid exceeding the permissible content of CO_2 in the finished gas, it is necessary to carefully select the optimal content of MDEA in this mixture. When switching to another absorbent, there may be some improvements related to several key aspects of the plant's operation. The transition to another absorbent is aimed at increasing sulphur yield, improving the economic efficiency of amine purification processes in sulphur production, and extending the service life of equipment. It is assumed that reducing the volume of absorbent recycling and the volume of water vapor supply for regeneration can help reduce the formation of COS and CS_2 compounds in the sulphur production process. These changes are aimed at improving the efficiency and safety of the plant, increasing its production capacity and reducing the negative impact on the environment [14; 15].

In the course of the study, modelling of the amine purification process was analyzed, where a DEA-MDEA mixture was used when the proportions of these amines changed. The obtained calculation results presented in Table 1 demonstrate the meaningfulness of the proposed engineering solutions and their practical applicability.

Table 1. Composition of acid gas at different ratios of amines

Absorbent	MDEA 70%: DEA 30% (35% solution)		DEA (40% solution)	
	Composition 1		Composition 2	
	kg/h	weight, %	kg/h	weight, %
Hydrogen sulphide	81,744.94	69.14	61,292.18	51.85
Carbon dioxide	32,034.59	27.11	52,466.35	44.4
Water	3,887.37	3.29	3,897.37	3.29
Methane	510.14	0.43	521.14	0.43
Methylmercaptan	35.46	0.03	35.46	0.03
Total	118,212.5	100	118,212.5	100

Source: compiled by the authors based on [16]

The proposed improvement in the amine purification process, the replacement of diethanolamine with its mixture with methyldiethanolamine, represents a significant technical change aimed at improving the efficiency of the process and ensuring the required quality of the final gas product. Replacing DEA with a combined solution with MDEA allows increasing the concentration of H_2S in acid gases, which is a key factor in the process of amine purification. This improvement assumes that the amine mixture will contribute to the efficient extraction of the required amount of CO_2 in accordance with the requirements for its content in the finished gas product. This is important because the final CO_2 content in the commercial gas must meet strict quality standards, and its regulation plays an essential role in the purification process [17; 18]. Mixing DEA with MDEA is also aimed at ensuring an optimal balance between the content of CO_2 and H_2S in the gases representing the output product. This technical solution is aimed at improving the amine purification process, providing more precise control and high efficiency in the production of a gas product that meets the required standards and specifications.

The use of alkanolamines in the purification process also faces a serious problem associated with the thermochemical decomposition of the absorbent under the influence of CO_2 contained in acid gases. As a result of this reaction, nitrogen-containing organic compounds arise, which have a negative effect on the absorbent. These compounds increase the viscosity of the absorbent, reduce its ability to absorb gases and contribute to the foaming, which complicates and slows down the gas purification process. This is an important problem, since the degradation of the absorbent negatively affects the efficiency of the purification process and requires additional measures to maintain its operability. This problem can be overcome by filtration and sorption purification or by influencing various factors affecting the decomposition of amine compounds. This includes manipulating the composition of the gas, optimizing the operating mode of the absorber and desorber, and monitoring the presence of impurities in the amine solution itself. The measures taken are aimed at minimising the effects of CO_2 on amine compounds, which helps to improve the efficiency of the absorbent and increase the efficiency of the gas purification process.

During the absorption of CO_2 by a DEA solution, a chemical reaction occurs, leading not only to the formation of one substance, but also to a number of decomposition by-products. The key factor determining the type and number of compounds that occur is CO_2 itself. The use of DEA as an absorbent is especially interesting because its main decomposition product becomes N,N-di(2-hydroxyethyl)-piperazine (HEP) [19; 20]. It is worth noting that the HEP and its derivatives have non-corrosive activity, that is, they do not contribute to the corrosion of metals and equipment. Moreover, these decomposition products do not have a noticeable negative effect on the ability of diethanolamine to absorb new portions of CO_2, while maintaining its absorption qualities at a high level. This circumstance makes DEA especially valuable as an absorbent in industrial gas purification processes, where it is important not only to efficiently extract acid gases from streams, but also to maintain the stability and safety of operation of chemically treated equipment.

For a deep understanding of the effect of temperature on the decomposition of amines, especially when using diethanolamine as an absorbent for cleaning gases from CO_2, it is necessary to consider the following: at moderate temperatures of the order of 100°C and a pressure of about 1.2 MPa, the decomposition reaction of DEA due to CO_2 is very limited. However, with an increase in the temperature threshold to 175°C and an increase in pressure to 4.1 MPa, the percentage of amine decomposition increases sharply, and can reach 90% [19]. The rates of these chemical decomposition reactions may be low, but the consequences of their occurrence have a significant impact on the process of amine exploitation. Over time, regenerative compounds are gradually formed at high temperatures and pressures. These compounds accumulate in the system, which leads to a gradual decrease in the activity of the amine, an increase in the viscosity and tendency of the solution to foaming, and an increase in its corrosive activity [21]. All this affects the effectiveness of the presented gas purification method: the process is becoming less productive, requiring more frequent substitution of the amine solution or enhanced regeneration, which entails additional costs and technical difficulties in managing the process. Because of these factors, engineers and technologists working in the field of amine purification of gases must carefully approach the choice of temperature conditions and pressure in chemical devices. This is necessary to minimize the adverse effects of chemical decomposition reactions, maintain high absorption efficiency and prevent premature wear of equipment.

Figure 1 shows a diagram illustrating the change in the rate constant of chemical destruction of amines under the influence of CO_2 depending on temperature conditions. The graphic image clearly demonstrates that methyldiethanolamine is superior to diethanolamine in resistance to destructive processes, and with increasing temperature, this resistance is further enhanced, exacerbating the differences between these two substances.

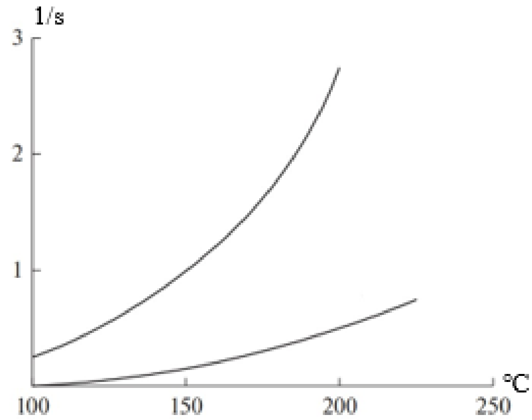


Figure 1. Change in the rate of thermochemical destruction of alkanolamines depending on temperature (at a pressure of C_2 above 0.1 MPa)

Source: compiled by the authors based on [16]

As already mentioned, the maximum decomposition of amine compounds is observed when they interact with high concentrations of CO_2, especially when the temperature regime reaches values in the region of 80-110°C. However, the amine regeneration process often requires even higher temperatures – up to 120-130°C. Under conditions of such heating, the molecules of even the most chemically stable alkanolamines are destroyed. Oxygen is a particular problem – it is an oxidation catalyst, contributing to the acceleration of the decomposition of amines. The oxygen source can be water, which is contained in industrial gases, and in the solution used for absorption. The appearance of foam during the removal of acidic contaminants from gases is also an acute problem affecting the efficiency of treatment systems. There are many factors that provoke the foaming. Among the main ones are:

– acceleration of corrosion processes in the equipment used;

– penetration of various foreign substances into the gas during its extraction;

– ingress of heavy hydrocarbon droplets into the absorption circuit;

– destruction of amines when exposed to high temperatures;

– accumulation of products of side chemical reactions and the results of the decomposition of the absorbent in the amine solution;

– presence of water droplets in the gas;

– content of mineral salts in industrial water used to create an absorbent solution.

All this contributes to the loss of the quality of the purified gas, leakage of the absorbent, disruption of the normal functioning of cleaning systems, reduction of their productivity, and pressure changes in the apparatus, which is the main indicator of the occurrence of foaming.

There are various approaches to combat this problem. Practical solutions include physical and mechanical methods, various technological approaches, and chemical methods. To prevent the accumulation of pollutants in the absorption solution, which can cause foaming, the absorbent is cleaned or regenerated. This is an important step in maintaining the efficiency and operation of the cleaning system, helping to prevent various undesirable chemical reactions and physical changes that can degrade performance and ultimately shorten the service life of the installation. Physical methods include: heat treatment, including both lowering the temperature through freezing and increasing it by heating or exposure to saturated steam; the use of electric current of various characteristics; the use of acoustic vibrations, in particular, ultrasonic frequency; operation of mechanical vibration; creating conditions for capillary pressure capable of destroying the foam structure. A particularly effective solution to the problem is the removal of impurities by constant filtration of the amine solution, which prevents the accumulation of substances that provoke the foaming, and maintains the continuous cleanliness of the system.

Chemical defoaming is the main method of combating the foaming in a process where special chemical reagents are used – anti-foaming agents and defoamers. Effective defoamers must have several key characteristics: high efficiency in the rapid destruction of foam, the ability to work at low concentrations and maintain their effect for a long time. They should also not change the properties and quality of the product, not create problems in subsequent processing, have no toxic effects, be resistant to high temperatures, and maintain stability during storage. These characteristics are necessary for effective foam control during the production process, ensuring the stability and quality of the cleaning process without negative effects on the product and the working environment [22]. Defoamers are classified depending on the method of introduction into the solution. Some of them are used in advance to prevent the foaming (anti-foaming agents), while others are introduced when the foam has already arisen (actually, defoamers). It should be noted that the use of defoamers before the appearance of foam is impractical, and anti-foaming agents lose their effectiveness after the foam has already formed. However, in the future, for convenience, all these chemical compounds will be generally referred to as defoamers.

Thus, to assess the effectiveness of defoamers, three key characteristics are taken into account: the ability to prevent foam formation, the duration of action in preventing foaming, and the effectiveness of eliminating foam when introduced into the medium. As a result of the analysis of the effectiveness of the used and proposed defoamers in the process of purifying natural gases from sulphur with amines, an improvement in the foam removal technology was proposed. This improvement consists in replacing the imported defoamer with a more effective composition that includes both a defoamer and an anti-foaming agent [23]. A detailed study of the performance of the plates in the absorber was also performed, and the material and energy balances of the absorber were compiled (Tables 2 and 3).

Table 2. Material balance of the absorber

Material balance			
Incoming material flow	**Mass consumption**	**Outgoing material flow**	**Mass consumption**
Gas	270,564.1 kg/h	Condensate	4,122.8 kg/h
Add. water 1	6,510.4 kg/h	Clean gas	155,230.8 kg/h
Add. water 2	19.5 kg/h	Combustible gas	1,442.1 kg/h
		Acid gas	1,165,111 kg/h
Total input flow	277,094 kg/h	Total output flow	277,287.6 kg/h

Source: compiled by the authors based on [24]

Table 3. Thermal balance of the absorber

Energy balance			
Incoming energy flow	**Amount of heat**	**Outgoing energy flow**	**Amount of heat**
Gas	35,302,653.8 kcal/h	Condensate	171,525.5 kcal/h
Q-102	72,479,462.9 kcal/h	Condensate	28,527,504 kcal/h
Add. water 1	-2,945,754.5 kcal/h	Combustible gas	168,844.7 kcal/h
Q-101	895,551.4 kcal/h	Q-101	3,671,261.1 kcal/h
Add. water 2	-8,911.9 kcal/h	Acid gas	8,476,185.9 kcal/h
Q-103	2,312,807.2 kcal/h	Q-100	21,638,483.7 kcal/h
		Q-102	45,214,093.4 kcal/h
Total input flow	108,035,808.9 kcal/h	Total output flow	107,867,868.4 kcal/h

Source: compiled by the authors based on [24]

The analysis identified certain disadvantages in the use of active defoaming agents: noticeable energy costs for their use, provoking the degradation of amines at the chemical and thermal levels, which entails losses of these compounds, and increased content of pollutants in amine solutions, including mechanical inclusions of various nature and heat-stable salt compounds. Based on the analysis, Figures 2 and 3 present an assessment of the effectiveness of several used defoamers and their analogues.

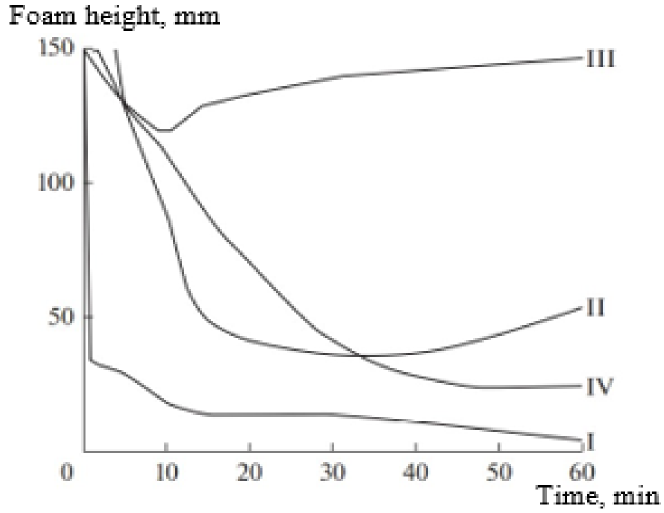


Figure 2. Dependence of foam height on time for various defoamers
Note: 1 – KPG-200AV (surfactants, 1 ml); 2 – Rhodorsil 411; 3 – DB-31; 4 – KPG-200AV (surfactant, 3 ml)
Source: compiled by the authors based on [24]

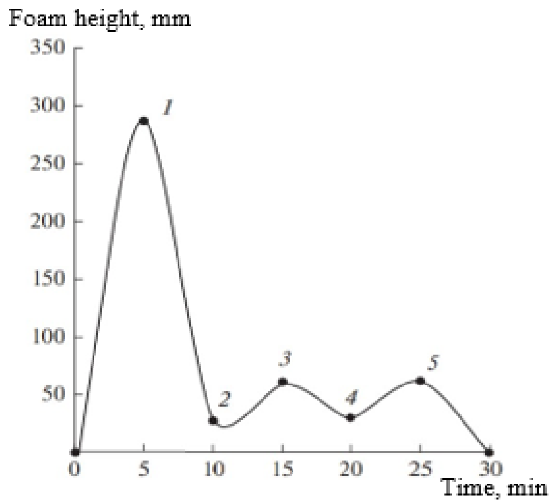


Figure 3. Defoaming characteristics of KPG-200
Note: 1, 3, 5 – defoamer supply; 2, 4 – minimum value of the foam height.
Source: compiled by the authors based on [24]

The graph in Figure 2 shows that the KPG-200AV defoamer demonstrates the highest efficiency in reducing the level of foaming. It is also noted that the KPG-200 defoamer exhibits strong properties in extinguishing foam, demonstrating effectiveness at the time of foaming, when it is introduced into the absorbent column. According to the results of the analysis of various proposals to reduce foaming and their comparison with data on industrial defoamers, it turned out that the optimal method of foam reduction technology is the joint use of defoamers KPG-200AV and KPG-200. The first defoamer is recommended to be added regularly in small quantities to prevent foaming, and the second is used at the moment of its appearance to eliminate it.

To reduce foaming, it is important to influence its main causes. In the process of foam formation, various non-wetting substances, such as impurities or corrosion products, tend to stick to gas bubbles, which ultimately increases the rate of foaming. These substances, when they become part of the foam, interact with high-boiling paraffin hydrocarbons, contributing to an additional acceleration of foaming. The approach to reducing foam formation also includes minimising the effects of these non-wetting substances and high-boiling hydrocarbons. This can be done by developing specialized anti-foam substances or by treating the mixture to prevent their effect on gas bubbles. The use of alkanolamines for gas purification ensures effective removal of impurities at a relatively low consumption of the alkanolamine itself. Despite this, the process of regeneration of the absorbent requires an additional energy contribution, as a result of which the total consumption of thermal energy increases. A standard gas purification scheme usually includes two key elements: an absorber and a desorber. Two main amine streams are placed in the absorber: partially regenerated amine moving from the middle of the desorber to the middle of the absorber, and fully regenerated amine, which enters the upper part of the absorber. This approach significantly reduces energy consumption in the amine regeneration process, which helps to increase efficiency and optimize the gas purification process.

The efficiency of cleaning processes is significantly increased when using schemes that use steam recompression. This method consists in transferring the regenerated amine from the desorber with a preliminary pressure reduction in the separator. The liquid phase of the separator, which is a carefully regenerated amine, is sent to the absorber. The steam phase undergoes compression and returns back to the desorber as an additional nutrient stream. The use of a gas purification scheme using steam recompression leads to the production of regenerated amine with a reduced content of acid gases, which contributes to an increase in the degree of purification in the absorber. It is also possible to create a hybrid of the last two schemes, where the carefully regenerated amine is divided into two streams: one is directed to the center of the absorber, and the second to the separator, from where the liquid phase enters the upper part of the absorber. It has been found that using this combination of schemes reduces steam consumption by about 11%. This allows optimizing the process and saving resources while maintaining high efficiency of gas purification [25; 26].

Another important feature of the purification process is that gases subjected to the removal of impurities using alkanolamine solutions often include a variety of components capable of entering into permanent chemical bonds with cleaning agents. Substances such as sulphur compounds and carboxylic acids, among others, react with alkanolamines to form heat-resistant ionic compounds called heat-stable salts (HSS). These salts are unique in that they cannot be eliminated from the alkanolamine solution even when heated, for example, in regeneration or desorption processes. Additional formation of HSS can be caused by the use of various chemical reagents, declared as "neutralizers", designed to optimize the purification process. In addition, the cause of the accumulation of these salts in the amine solution is also exogenous factors, such as salt penetration due to leakage of cooling systems and similar external influences. Thus, the accumulation of HSS in the system becomes a serious problem that requires special attention within the framework of gas purification technology.

There are several methods of purification of HSS from amine solutions. One method is vacuum distillation, in which reduced pressure helps to evaporate water and amines, leaving heat-stable salts eliminated from the mixture. The electrodialysis process is carried out through ion-exchange membranes, which allow the HSS ions to be carried to oppositely charged electrodes, thereby removing them from the solution. However, ion exchange is the most effective, cost-effective and environmentally friendly method of separating HSS from amine solutions. This method involves the use of resins capable of replacing HSS ions with less stable ions. This means that ionites, which function as polymer matrices with tightly bound functional groups, exchange their ions for ions of heat-stable salts, thereby liberating amine solutions from this type of impurities. Ionites are also preferable because they provide the possibility of regeneration and reuse, which reduces operating costs and minimizes environmental impact. The choice of a specific cleaning method will depend on the nature of the process, the economic feasibility and the environmental requirements facing the production. Vacuum distillation is a method in which the used amine solution is purified under low pressure conditions. The use of vacuum is conditioned by the need to prevent excessive losses of amine in the event of its boiling at standard atmospheric pressure, given the high boiling points of amines common in industry, such as MDEA and DEA. The reduced pressure in the system helps to minimize the entrainment of amines with water vapor, thereby increasing the efficiency of the process [23; 25].

The main advantage of this technique is its ability to completely remove substances such as HSS and water-soluble compounds (WSC) from the solution, and other components having significantly different boiling points from the boiling point of the amine used. In turn, the efficiency of removing impurities whose boiling point is close to the boiling point of the amine used may be limited due to overlapping boiling temperature ranges. These features make vacuum distillation a key choice in a set of amine purification methods aimed at optimizing their reuse and extending their service life. Combining the methods of ion exchange or electrodialysis with the procedure of intensive filtration through a layer of activated carbon also shows significant efficiency in the purification of amine solutions. Ion exchange and electrodialysis are aimed at ridding the solution of HSS, while passing the solution through activated carbon helps to remove high-molecular substances resulting from thermal and chemical degradation processes, and the formation of resinous products. This combination of methods is particularly effective for eliminating bicine, a dangerous corrosive impurity often formed during the decomposition of MDEA. In addition, the use of these technologies allows the regeneration of amine directly in its aqueous solution, which eliminates the need for an additional stage of water removal. This approach leads to increased process efficiency and reduced overall maintenance costs of the amine purification system.

Some limitations of the process include the inability to completely extract the amine breakdown products, which may have different levels of volatility. These substances are intermediate and final elements of the chemical degradation of amine and can vary in their physical properties. In addition, filtration efficiency can be significantly reduced in the presence of certain surfactants in solution, for which even enhanced filtration through activated carbon may be ineffective. These surfactants can contribute to the appearance of stable foam, which makes the recycled amine solution prone to increased foamability. This feature requires additional attention when optimizing the process, since the increased foaming capacity can interfere with the effective operation of the cleaning system and requires the use of additional anti-foam adjustments. The use of ion exchangers for the extraction of heat-stable salts from amine solutions is an important addition to standard filtration systems used in industry. Standard filters are designed to eliminate insoluble components by their use and cannot effectively remove dissolved total dissolved solids (TDS) from absorbents. On the other hand, ion exchange specializes in the removal of precisely this kind of soluble ionic impurities. However, this method has limitations: the ion exchanger is not able to capture and remove small organic fractions, products of chemical degradation of amines, heavy hydrocarbons, resinous substances and surfactants that can accumulate in the absorbed solution. These pollution elements require other cleaning approaches and technologies to maintain the efficiency of the absorption system and prevent its premature wear and loss of functionality. Thus, full-fledged maintenance and operability of absorption systems requires an integrated approach, including not only ion exchange, but also the use of additional separation and purification techniques capable of separating or processing a wide range of pollutants [27-30].

Thus, within the framework of the study, a thorough analysis of the difficulties associated with the process of amine gas purification was carried out, based on which methods for solving the identified shortcomings were developed. The main measures included several important points:

1. It is a careful selection of components for the development of the most suitable combination of alkanolamines in terms of efficiency and stability.
2. Strict observance of the established parameters of the technological process, which includes proper regulation of temperature and pressure to ensure the most efficient operation of the system.
3. The initiation of measures, which prevent harmful impurities from entering the absorbent solution, protecting it from contaminants that contribute to corrosion and create deposits.
4. The introduction of special additives – defoamers that reduce foaming and improve the overall functionality of amine purification systems.

All these steps are aimed at improving the quality of cleaning operations, saving maintenance resources, and improving the safety and operational reliability of production procedures, which has a significant impact on the efficiency of the entire gas purification system. The practical implementation of the proposed solutions allows achieving a cleaner final product, reducing the loss of valuable components, and lowering the environmental impact by reducing emissions of pollutants. It is also worth emphasizing that taking measures to optimize the operation of amine cleaning systems helps to prevent premature wear of equipment and, accordingly, reduce the cost of its repair or replacement. This, in turn, increases the intervals between scheduled maintenance shutdowns and increases the overall productivity of the enterprise.

Discussion

Research aimed at optimizing the technology of amine gas purification from acidic components plays a key role in modern industry and energy. Gas purification from acidic impurities such as H_2S and CO_2 are of great importance to ensure the high quality of the final gas product. Such research is an integral part of the drive to improve energy production processes, the petrochemical and chemical industries, and other industries where the use of natural gases is a key component of production. An important feature is that acidic components such as H_2S can be used in various production processes. For example, H_2S can be used to produce sulphuric acid, sulphur and various sulphur-containing compounds, which are widely used in industry, in the production of fertilizers, plastics, and in the production of iron and steel [31; 32]. In addition, H_2S can be extracted and processed for use in energy production, in particular, in the hydrogen production process or as an energy carrier in various technologies, which indicates the importance of further study and improvement of purification processes.

M. Afkhamipour & M. Mofarahi [33] noted that the different compositions of amines can affect the efficiency of H_2S removal in the natural gas purification process in different ways. Some amines exhibit high selectivity towards H_2S, which allows absorbing and removing it from gas streams more efficiently. It was noted that the correct choice of their composition can contribute to improving the purity of the gas used in various industrial processes and in domestic conditions. This study highlights the importance of choosing different amines for effective purification of H_2S gas, emphasizing that the optimal choice of amine composition affects the quality of the purified gas. At the same time, the study confirms the effect of the ratio of amines on the content of H_2S and CO_2 in the finished product. Both studies emphasize that the correct choice of amines and their ratios significantly affects the purity and quality of the gas, and the durability of the purification process and equipment, which is critically important for the efficiency of gas flow production.

M. Mohamadi-Baghmolaei *et al.* [34] emphasized that the choice of the optimal amine concentration in a circulating aqueous solution is the result of considering several variables. This choice is not limited by strict rules and depends on various circumstances. It was noted that the type of gases being processed has a significant impact on this process: whether it is crude natural gas or refined by-gases with a low content of H_2S and CO_2, or gases with a high percentage of CO_2. It is also noted that the variability of the composition of the treated gases requires a flexible approach to determining the optimal amine concentration, considering the characteristics of each process and its needs. This study indicates flexibility and ambiguity in determining the optimal amine concentration for gas purification. The approach to the choice of amine concentration is not regulated by strict rules, which allows considering various variables, such as the type of gases being treated and their composition. However, such flexibility can present its own difficulties and disadvantages. Such a flexible approach requires constant analysis and customization, which can complicate the management and control processes in industrial production.

F. Meng *et al.* [35] demonstrated that the optimal way to dispose of an exhausted amine solution can be disposal in thermal neutralization furnaces. This disposal method involves heating the exhausted solution to high temperatures in special furnaces, which allows the decomposition of amine compounds to safer or less toxic compounds. It is argued that the approach can be effective in reducing the content of hazardous substances in waste to levels that meet safety standards, which plays an important role in compliance with environmental standards and requirements for the disposal of industrial waste. The results of the study emphasize the importance of choosing the optimal method for recycling exhausted amine solutions in industrial processes, which complements the results obtained in this study. It is indicated that disposal in thermal neutralization furnaces can be an effective approach to reducing the content of hazardous substances in waste to levels that meet safety standards [36]. Given the importance of industrial waste treatment for environmental sustainability and compliance, this study shows that choosing the right disposal method plays a key role in minimising negative environmental impacts.

According to S. Kar *et al.* [37], another effective way to dispose of the exhausted amine solution is its separation and subsequent processing. In this method, the amine solution was distilled at atmospheric pressure and temperatures up to 160°C, which allowed the water to be separated from the amine. The resulting aqueous distillate was neutralized, forming a solution of surfactants. The residue from distillation was distilled in a vacuum, separating three fractions, of which the second (containing 98-99.6% monoethanolamine) was used as a commercial product. The third fraction, neutralized with acid, has found application as a reducing agent in the production of leather and fur. This approach ensured the complete recycling of the exhausted amine solution, which not only reduced the amount of waste, but also allowed the reuse of valuable components of the solution, respecting the environmental and economic aspects of production [38]. The study also indicates the importance of a variety of methods for recycling exhausted amine solutions. It shows that the process of amine gas purification requires a flexible and carefully thought-out approach to the disposal of exhausted solutions [39; 40]. This study, complementing these conclusions, shows that the optimization of the technology of amine purification from acid gases significantly affects the production of gas streams. Similar studies once again emphasize the importance of environmental sustainability and efficient use of resources in production processes.

In general, all the studies mentioned above show a variety of aspects that require further research to create more effective and sustainable strategies for cleaning gas streams. Further research should also focus on the development of new materials and technologies that can improve the efficiency and stability of the cleaning process, reduce harmful effects on the environment, and ensure compliance with quality standards. The development of research in this area will not only contribute to the improvement of technological processes in industry, but also contribute to the preservation of environmental sustainability and the efficient use of natural resources.

Conclusions

As a result of the conducted research, which includes the analysis of a number of experiments, it was found that the optimization of the technology of amine purification from acid gases has a significant impact on the efficiency of gas flow production. The analysis of the conducted experiments revealed that the optimization of the amine gas purification process significantly affects the composition of the acid gas.

When using different ratios of MDEA and DEA in solutions, it was found that an increase in the content of MDEA in the absorbent (70% MDEA and 30% DEA) leads to a significant decrease in the content of H_2S in acid gas to 69.15 kg/h. The CO_2 content is also changing, increasing from 27.1% to 44.4%, which is an important factor for determining the compliance of the finished gas product with the requirements of quality standards. These changes emphasize the importance of selecting optimal amine ratios to achieve the desired gas composition after purification. The decomposition of amines with increasing temperature has also been shown to be important: at 100°C and a pressure of 1.2 MPa, the decomposition of diethanolamine by CO_2 (CO_2) is negligible, but at higher temperatures, 175°C and a pressure of 4.1 MPa, up to 90% of the amines decompose. This is of serious importance, given that irreversible compounds accumulate in the apparatus over time, and then leads to a decrease in the activity of the amine, an increase in the viscosity and foamability of the solution, and increased corrosion activity. Moreover, based on the analysis of various proposals for reducing foaming compared with data on industrial defoaming agents, it was determined that the best option for defoaming technology is a combination of the KPG-200AV with the KPG-200 defoamers. The first is recommended to be used continuously, adding small fractions to prevent the formation of foam, the second – when foam appears to eliminate it. All the data obtained are an important step in optimizing the process of amine purification of gas from acidic components. They provide a basis for decision-making aimed at improving the efficiency of cleaning operations, improving the quality of gas product production and ensuring compliance with quality standards.

For further research in the field of amine gas purification from acidic components, an in-depth analysis of the effect of temperature, pressure, and concentration of amines on decomposition and degradation processes is recommended, and the study of new compounds to increase the resistance of amines to the action of acidic components. The practical significance of the results obtained lies in the possibility of more precise control and optimization of gas purification processes, which will lead to increased production efficiency, reduced energy consumption, and higher quality of the final gas product.

Acknowledgements
None.

Conflict of Interest
None.

References
[1] Lyubchik SB, Perepichka II, Galushko OL, Lyubchik AI, Lygina ES, Fonseca IM. Optimization of the conditions for the Cr (III) adsorption on activated carbon. *Adsorption.* 2005;11(5-6):581-593. DOI: 10.1007/s10450-005-5616-1.
[2] Moldabayeva G, Suleimenova R, Buktukov N, Mergenov M. Improvement of oil field development using enhanced oil recovery methods. *Nauk Visn Nats Hirnych Univers.* 2021;6:23-28. DOI: 10.33271/nvngu/2021-6/023.
[3] Moldabayeva GZ, Suleimenova RT, Akhmetov SM, Shayakhmetova ZB, Suyungariyev GE. The process of monitoring the current condition of oil recovery at the production fields in Western Kazakhstan. *J Appl Engin Sci.* 2021;19(4):1099-1107. DOI: 10.5937/jaes0-30840.
[4] Grigore E, Pantea O, Bombos D, Calin C, Bondarev A, Gheorghe C. Effect of inhibitors based amine derivates on some carbon steel corrosion. *Rev Chim.* 2015;66(5):685-690.
[5] Fialko NM, Prokopov VG, Meranova NO, Borisov YS, Korzhik VN, Sherenkovskaya GP. Thermal physics of gasothermal coatings formation processes. State of investigations. *Fiz Khim Obrab Mater.* 1993;4:83-93.
[6] Ivanov NS, Abilmagzhanov AZ, Adelbayev IY, Nurtazina AE. Comparative evaluation of diethanolamine solution purification technologies from heat-stable salts and bonded amine. *News Nat Acad Sci Rep Kazakh S Chem Tech.* 2020;1(439):72-8. DOI: 10.32014/2020.2518-1491.9.
[7] Akurpekova AK, Nefedov AN, Dalelhanuly O, Tastemirova AT, Abilmagzhanov AZ. Study of aqueous solutions of methyldiethanolamine used for gas purification. *News Nat Acad Sci Rep Kazakh S Chem Tech.* 2021;5-6(449):6-13. DOI: 10.32014/2021.2518-1491.70.
[8] Daminov T, Shokhsuvorovich S, Abdurakhmanova S. Technologies used in natural gas dehydration: Problems and solutions. *E3S Web Conf.* 2024;497:01023. DOI: 10.1051/e3sconf/202449701023.
[9] Kemelzhanova A, Mukasev K, Yar-Mukhamedova G, Lampke T. Investigation of the anticorrosion properties of nano-CEC in amine environments. *Comp Use Mineral Res.* 2020;313(2):52-7. DOI: 10.31643/2020/6445.17.
[10] Ismagilov FR, Akhmetov SM, Jexenov MK, Diarov M. Method for adsorption purification of associated oil gases from mercaptans. *News Nat Acad Sci Rep Kazakh S Chem Tech.* 2020;6(444):79-86. DOI: 10.32014/2020.2518-1491.101.
[11] Shang J, Qiu M, Ji Z. Efficiency improvement, consumption reduction and optimization of high-sulfur natural gas sweetening units. *Nat Gas Ind B.* 2019;6(5):472-480. DOI: 10.1016/j.ngib.2019.02.004.
[12] Korzhik VN. Theoretical analysis of the amorphization conditions for metallic melts under gas-thermal spraying. I. Determination of cooling velocities of dispersed sprayed material. *Poroshk Metall.* 1992;9:56-61.
[13] Korzhik VN. Theoretical analysis of conditions for metallic alloy amorphization on gas thermal deposition. 2. Phase formation under solidification of deposited material. *Poroshk Metall.* 1992;10:11-15.
[14] Yang M, Feng X. Simulation-based optimization and design of refinery hydrogen networks with hydrogen sulfide removal. *Int J Hydrog Energy.* 2019;44(43):23833-23845. DOI: 10.1016/j.ijhydene.2019.07.108.
[15] Bondarev A, Mihai S, Pântea O, Neagoe S. Use of biopolymers for the removal of metal ion contaminants from water. *Macromol Symp.* 2011;303(1):78-84. DOI:10.1002/masy.201150511.
[16] Ghorbani A, Bayati B, Drioli E, *et al.* Modeling of nanofiltration process using DSPM-DE model for purification of amine solution. *Membranes*. 2021;11(4):230. DOI: 10.3390/membranes11040230.
[17] Xia Z, Wang S, Zhou L, *et al.* Surrogate-assisted optimization of refinery hydrogen networks with hydrogen sulfide removal. *J Clean Prod.* 2021;310:127477. DOI: 10.1016/j.jclepro.2021.127477.
[18] Fialko NM, Prokopov VG, Meranova NO, Borisov YS, Korzhik VN, Sherenkovskaya GP. Single particle-substrate thermal interaction during gas-thermal coatings fabrication. *Fiz Khim Obrab Mater.* 1994;1:70-78.
[19] Knyazeva AK, Rakhimov MN, Evdokimova NG, Akhmetov RF. Selection of absorbent and technological parameters for purification of natural gas with equal ratio of acidic components. *Chem Technol Fuels Oils.* 2022;58(3):454-458. DOI: 10.1007/s10553-022-01405-4.
[20] Mihai S, Bondarev A, Negoiu M. Complexes of Pt(II) and Pd(II) with symmetrical bipodal N,N-bis-antipyrine-N'pyridinethioureas. *Rev Chim.* 2013;64(2):191-194.
[21] Prokopov VG, Fialko NM, Sherenkovskaya GP, Yurchuk VL, Borisov YS, Murashov AP, Korzhik VN. Effect of coating porosity on the process of heat transfer with gas-thermal deposition. *Powder Metall Met Ceram.* 1993;32(2):118-121.
[22] Igamkulova NA, Mengliev ShSh, Rakhimov KhN, *et al.* Degradation of ethanolamines and reducing their impact on devices. *AIP Conf Proc.* 2023;2789(1):060001.

[23] Jia W, Xian C, Wu J. Temperature-sensitive foaming agent developed for smart foam drainage technology. *RSC Adv.* 2022;12(36):23447-23453. DOI: 10.1039/D2RA04034D.

[24] Golubeva IA, Dashkina AV, Shulga IV. Demanding problems of amine treating of natural gas: Analysis and ways of solution. *Pet Chem.* 2020;60:45-50. DOI: 10.1134/S0965544120010089.

[25] Zhang R, He X, Liu T, *et al.* Thermodynamic studies for improving the prediction of CO_2 equilibrium solubility in aqueous 2-dimethylamino-2-methyl-1-propanol. *Sep Purif Technol.* 2022;295:121292. DOI: 10.1016/j.seppur.2022.121292.

[26] Abdibattayeva M, Bissenov K, Zhubandykova Z, Orynbassar R, Tastanova L, Almatova B. Purification of oil-containing waste using solar energy. *Environ Clim Technol.* 2021;25(1):161-175. DOI: 10.2478/rtuect-2021-0011.

[27] Wu X, ElMoudir W, Aboudheir A, Mahinpey N. Reclaiming degraded mixed monoethanolamine and N-methyldiethanolamine solvent in carbon dioxide capture process. *J Natur Gas Sci Eng.* 2021;95:104214. DOI: 10.1016/j.jngse.2021.104214.

[28] Bolatbek K, Ivanov SI, Gordienko MG, Menshutina NV. Mathematical modeling of aerogel structures, including with embedded carbon nanotubes. *Int Multidisc Sci GeoConf Surv Geol Min Ecol Manag, SGEM*. 2016;3(BOOK 6):69-76.

[29] Borisov YS, Oliker VE, Astakhov EA, Korzhik VN, Kunitskii YA. Structure and properties of gas-thermal coatings of Fe-B-C and Fe-Ti-B-C alloys. *Sov Powder Metall Met Ceram.* 1987;26(4):313-318.

[30] Fialko NM, Prokopov VG, Meranova NO, Borisov YS, Korzhik VN, Sherenkovskaya GP. Temperature conditions of particle-substrate systems in a gas-thermal deposition process. *Fiz Khim Obrab Mater.* 1994;2:59-67.

[31] Shalbolova UZ, Narmanova RA, Tlessova EB, Ryskulova Z. Economic efficiency of cold oil bituminous mastic production. *Espac.* 2017;38(46):36.

[32] Fialko NM, Prokopov VG, Meranova NO, Borisov YS, Korzhik VN, Sherenkovskaya GP. Heat transport processes in coating-substrate systems under gas-thermal deposition. *Fiz Khim Obrab Mater.* 1994;2:68-75.

[33] Afkhamipour M, Mofarahi M. Effects of operating parameters of packed columns on the $K_{G}a_{v}$ for CO_2 absorption by amine solutions using optimization-simulation framework. *Sep Purif Technol.* 2018;202:86-102. DOI: 10.1016/j.seppur.2018.03.026.

[34] Mohamadi-Baghmolaei M, Hajizadeh A, Zahedizadeh P, Azin R, Zendehboudi S. Evaluation of hybridized performance of amine scrubbing plant based on exergy, energy, environmental, and economic prospects: A gas sweetening plant case study. *Energy*. 2021;214:118715. DOI: 10.1016/j.energy.2020.118715.

[35] Meng F, Meng Y, Ju T, *et al.* Research progress of aqueous amine solution for CO_2 capture: A review. *Renew Sustain Energy Rev.* 2022;168:112902. DOI: 10.1016/j.rser.2022.112902.

[36] Metaksa G, Moldabaeva G, Alisheva Z. Obtaining preset properties in the hydrogenation process by controlling the state of phase boundary. *E3S Web Conf.* 2018;56:03028. DOI: 10.1051/e3sconf/20185603028.

[37] Kar S, Goeppert A, Prakash GKS. Combined CO_2 capture and hydrogenation to methanol: Amine immobilization enables easy recycling of active elements. *ChemSusChem*. 2019;12(13):3172-3177. DOI: 10.1002/cssc.201900324.

[38] Sydorchuk P, Khlyap G, Andrukhiv A. Growth and some properties of heterostructures based on new narrow-gap semiconductor ZnCdHgTe. *Cryst Res Technol.* 2001;36(4-5):361-369. DOI: 10.1002/1521-4079(200106)36:4/5<361::AID-CRAT361>3.0.CO;2-5.

[39] Bolatbek K, Shlygina IA, Brodskiy AR, Ivanov SI, Gordienko MG. Quantum-chemical research methods of geometrical and electronic structure of silicon dioxide aerogels. *Int Multidisc Sci GeoConf Surv Geol Min Ecol Manag, SGEM*. 2016;3(BOOK 6):135-142.

[40] Bolatbek K, Brodskiy AR, Ivanov SI, Gordienko MG, Menshutina NV. Modeling of substances adsorption process in aerogel pores. *Int Multidisc Sci GeoConf Surv Geol Min Ecol Manag, SGEM*. 2016;3(BOOK 6):83-90.

Оптимізація технології очищення амінних газів від кислих компонентів

Гульсум Муратівна Муратова*
Магістр
Казахсько-Британський технічний університет
050000, вул. Толе бі, 59, м. Алмати, Республіка Казахстан
https://orcid.org/0009-0009-7506-5531

Михайло Костянтинович Тарабрін
Магістр
Абердинський університет
AB24 3FX, Королівський коледж, м. Абердін, Велика Британія
https://orcid.org/0000-0002-1419-530X

Анотація

Актуальність. Актуальність дослідження процесів очищення амінних газів проявляється в постійній необхідності вдосконалення цієї технології для ефективного зменшення викидів шкідливих речовин в атмосферу та в пошуку більш ефективних, енергозберігаючих та екологічно безпечних методів очищення газових потоків.

Мета. Метою даного дослідження є аналіз ефективності існуючих методів очищення амінних газів від кислотних компонентів для визначення найбільш оптимального та ефективного підходу, що забезпечить високий ступінь чистоти очищеного газу.

Методологія. Для досягнення поставленої мети використовували статистичний метод, порівняльний метод та аналіз.

Результати. В результаті дослідження було проведено детальну оцінку ключових проблем і недоліків, пов'язаних з процесом очищення амінів. В рамках цього були визначені основні фактори, що впливають на ефективність існуючої технології газоочищення. Серед запропонованих рішень було визначено важливість ретельного підбору оптимального складу алканоламінової суміші. Це важливе відкриття підкреслило важливість складу для забезпечення відповідності готового газового продукту стандартам якості. Це також є важливим кроком для підтримання оптимальних умов технологічного режиму, що сприяє більш ефективній роботі систем газоочищення.

Висновки. Всі пропозиції та удосконалення, розроблені в ході досліджень, мають суттєве практичне застосування. Їх впровадження дозволяє знизити енерговитрати та підвищити ефективність очищення газів від кислих компонентів, що дає змогу підприємствам впроваджувати більш ефективні методи очищення газів та підвищувати якість продукції.

Ключові слова: алканоламіни; піноутворення; абсорбент; реагенти; фільтрація; підвищення ефективності.