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ABSORBER COLUMN CONSTRUCTION AND EFFICIENCY

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Annotatsiya: Tabiiy gazni nordon komponentlardan tozalaşda qöllaniladigan absorber kolonnalarining konstruksiyasi, işlaş prinsipi va texnologik samaradorligi tahlil qilinadi. Vodorod sulfid (H_2S) va karbonat angidrid (CO_2) kabi nordon komponentlarni amin eritmalari yordamida ajratib olişga alohida e'tibor qaratiladi. Nasadkali va tarelkali absorberlarning konstruktiv xususiyatlari, gaz-suyuqlik kontakt mexanizmlari hamda massa almaşinuvi samaradorligiga ta'sir etuvçi asosiy omillar körib çiqiladi. Bosim, harorat, amin konsentratsiyasi, erituvçi sarfi va samarali kontakt yuzasining absorbsiya samaradorligiga ta'siri tahlil qilinadi. Şuningdek, töyingan amin eritmasini regeneratsiya qiliş jarayoni va umumiy absorbsiya-regeneratsiya tizimining energetik samaradorligi örganiladi. Adabiyotlar tahlili asosida absorber konstruksiyasini takomillaştiriş, massa almaşinuvi samaradorligini oşiriş va energiya sarfini kamaytiriş böyiça amaliy yondaşuvlar taklif etiladi.

Kalit sözlar: absorber kolonnasi, absorbsiya, massa almaşinuvi, tabiiy gaz, nordon gazlar, H_2S, CO_2, amin eritmasi, nasadkali kolonna, tarelkali kolonna, gaz-suyuqlik kontakti, massa almaşinuvi koeffitsiyenti, regeneratsiya, texnologik samaradorlik.

Аннотация: Проведён анализ конструкции, принципа работы и технологической эффективности абсорбционных колонн, применяемых для очистки природного газа от кислых компонентов. Особое внимание уделено удалению сероводорода (H_2S) и диоксида углерода (CO_2) с использованием аминовых растворов. Рассмотрены конструктивные особенности насадочных и тарельчатых абсорберов, механизмы контакта газа и жидкости, а также основные факторы, влияющие на эффективность массопереноса. Проанализировано влияние давления, температуры, концентрации амина, расхода растворителя и эффективной площади межфазного контакта на эффективность абсорбции. Также рассмотрены процесс регенерации насыщенного аминового раствора и энергетическая эффективность общей системы абсорбции и регенерации. На основе анализа научной литературы предложены практические подходы к совершенствованию конструкции абсорберов, повышению эффективности массопереноса и снижению энергопотребления.

Ключевые слова: абсорбционная колонна, абсорбция, массоперенос, природный газ, кислые газы, H_2S, CO_2, аминовый раствор, насадочная колонна, тарельчатая колонна, контакт газа и жидкости, коэффициент массопереноса, регенерация, технологическая эффективность.

Abstract: The design, operating principles, and technological efficiency of absorber columns used for natural gas sweetening are analyzed. Particular attention is paid to the removal of acidic components, such as hydrogen sulfide (H_2S) and carbon dioxide (CO_2), using amine solutions. The structural features of packed and tray absorbers, gas–liquid contact mechanisms, and the main factors affecting mass transfer efficiency are examined. The effects of pressure, temperature, amine concentration, solvent flow rate, and effective interfacial contact area on absorption efficiency are analyzed. The regeneration of rich amine solutions and the energy efficiency of the overall absorption–regeneration system are also discussed. Based on a review of the scientific literature, practical approaches to improving absorber design, enhancing mass transfer efficiency, and reducing energy consumption are proposed.

Keywords: absorber column, absorption, mass transfer, natural gas, acid gases, H_2S, CO_2, amine solution, packed column, tray column, gas–liquid contact, mass transfer coefficient, regeneration, technological efficiency.

INTRODUCTION

During natural gas processing, the removal of acidic components such as hydrogen sulfide (H_2S) and carbon dioxide (CO_2) is an important technological task. These components can affect gas quality, contribute to equipment corrosion, and influence the stability of technological processes. Therefore, absorption, particularly amine absorption, is widely used in natural gas treatment systems. Absorption is a mass transfer process involving the transfer of certain components from the gas phase into the liquid phase. During amine absorption, H_2S and CO_2 are

transferred from the gas phase into the amine solution through physical and chemical interactions. The efficiency of this process depends on the absorber column design, gas and liquid flow rates, pressure, temperature, solvent concentration, and effectiveness of gas–liquid contact.

The absorber column is typically a vertical cylindrical apparatus that facilitates countercurrent flow of the gas and liquid phases. Within the apparatus, gas flows upward from the bottom, while the amine solution flows downward from the top. This countercurrent flow helps maintain the driving force for mass transfer and facilitates deeper gas purification. Selecting an appropriate absorber design contributes to improving natural gas purification efficiency while optimizing hydraulic resistance, energy consumption, and operating costs. Therefore, a comprehensive analysis of absorber construction and performance is of considerable scientific and practical importance.

LITERATURE REVIEW

The theoretical foundations of absorption processes and mass transfer equipment have been extensively examined in studies by domestic and foreign researchers. Domestic scientific literature pays particular attention to absorber design, operating principles, and calculation methods. The theoretical foundations of mass transfer processes, the structural characteristics of absorbers, and methods for their calculation are described in detail in the textbook by Z. Salimov [1]. The second volume of this textbook focuses specifically on mass transfer processes and equipment, providing theoretical and practical foundations for absorber analysis. Salimov's approach provides a fundamental basis for studying absorbers, while modern natural gas processing systems also require consideration of energy efficiency and the hydrodynamic characteristics of new-generation packing materials. The textbook by N. R. Yusupbekov, X. S. Nurmuhamedov, and S. G. Zakirov, "Basic Processes and Devices of Chemical Technology," systematically examines the fundamental processes of chemical technology, the design of typical equipment, operating principles, and calculation methods [2]. An important feature of this source is its comprehensive examination of the relationship between technological processes and equipment design. Based on the authors' approach, it is appropriate to evaluate absorber efficiency not only through the mass transfer coefficient but also in conjunction with the hydrodynamic and structural characteristics of the equipment.

Foreign researchers G. Q. Wang, X. G. Yuan, and K. T. Yu analyzed correlations used to calculate mass transfer in packed columns. They compared the theoretical foundations, applicability limits, and principal parameters of various mass transfer correlations [3]. Their study indicates that the use of a single universal correlation may not fully account for the operating characteristics of different absorbers. Accordingly, the physical properties of the gas and liquid, packing type, and operating conditions should be considered when selecting a calculation model. L. Hegely, J. Roesler, P. Alix, D. Rouzineau, and M. Meyer comprehensively analyzed methods for determining the mass transfer coefficient and effective interfacial area in packed absorbers [4]. The researchers emphasized the importance of experimental accuracy, practical applicability, and packing layer height in determining mass transfer parameters. The findings of this study, published in the AIChE Journal of the American Institute of Chemical Engineers, highlight the importance of considering effective interfacial contact area as a key criterion when selecting an absorber design. The application of amine solutions in natural gas purification has been extensively reviewed by A. L. Kohl and R. B. Nielsen, as well as A. J. Kidnay et al. [5, 6]. These sources examine gas purification processes, the absorption of acidic gas components by amine solutions, and solvent regeneration processes. M. Yusuf et al. analyzed the selection of different amines for natural gas purification [7]. These studies indicate that solvent selection directly influences absorber efficiency, regeneration energy requirements, and the degree of gas purification.

The literature analysis indicates that domestic research primarily emphasizes the theoretical foundations, design, and calculation principles of absorbers, whereas foreign studies place greater emphasis on determining mass transfer parameters, developing advanced packing materials, and improving energy efficiency. Integrating these approaches can provide a more comprehensive assessment of absorber column efficiency. Accordingly, the selection of an optimal absorber design should involve a combined evaluation of mass transfer efficiency, hydraulic resistance, energy consumption, and the required degree of gas purification.

RESEARCH METHODOLOGY

The research methodology is based on the collection, systematization, and comparative analysis of scientific literature and technical information related to absorber column construction and efficiency. The primary sources of information include scientific articles, textbooks, technical publications, and previous studies on gas absorption, mass transfer processes, and natural gas purification technologies. Relevant data were obtained through a systematic review of published research addressing packed and tray absorbers, amine absorption processes, and solvent regeneration systems. The collected information was analyzed using descriptive, comparative, and analytical methods to evaluate the structural characteristics and operating principles of different absorber designs. Particular

attention was given to examining the relationships between pressure, temperature, amine concentration, solvent flow rate, effective interfacial contact area, and absorption efficiency. The comparative analysis was used to identify technological factors influencing mass transfer performance, hydraulic resistance, and energy consumption.

ANALYSIS AND RESULTS

The design and operating principle of the absorber column. The main structural elements of a packed absorber column include the column shell, packing layers, packing support grids, liquid distributors, redistributors, and devices for introducing and removing gas and liquid streams. In packed columns, gas and liquid maintain continuous contact over the surfaces of the packing elements. The packing may consist of regularly arranged structured elements or randomly distributed packing elements. Their primary function is to increase the effective interfacial contact area between the gas and liquid phases. Support grids are installed to hold the packing layers. In columns containing several packing layers, liquid redistribution devices are also used. These devices help minimize liquid flow along the column walls and ensure uniform distribution across subsequent packing layers. In tray absorbers, gas flows upward through openings, valves, or bubble caps in the trays. The liquid flows across the trays, forming a liquid layer. Consequently, each tray provides a separate stage of mass transfer between the gas and liquid phases.

Table 1. General comparison of packed and tray absorbers

Comparison criterion	Packed absorber	Tray absorber
Contact formation	Continuous contact over the packing surface	Stagewise contact on trays
Pressure loss	Usually lower	Relatively higher
Liquid distribution	Strongly dependent on the distributor	Depends on the tray design
Mass transfer	Efficient due to the large contact surface	Effective due to stagewise contact
Application	When a large contact surface is required	For high gas flow rates and when stagewise contact is required

As shown in the table, both absorber designs offer specific advantages. Packed absorbers generally provide relatively low pressure losses, while tray absorbers facilitate stagewise mass transfer. Therefore, the selection of an appropriate absorber type should be based on the specific operating conditions and technological requirements of the process.

Influence of technological parameters on absorption efficiency. The efficiency of an absorber column is determined by the interaction between the gas and liquid streams. The principal process parameters include pressure, temperature, amine concentration, solvent flow rate, and effective interfacial contact area.

Effect of pressure. An increase in pressure, under otherwise constant conditions, can increase the partial pressure of gas components and enhance their absorption into the liquid phase. During natural gas purification using amine solutions, elevated pressure can create favorable conditions for mass transfer. At the same time, increasing pressure requires appropriate mechanical strength of the apparatus and consideration of capital investment costs.

Effect of temperature. Temperature is an important parameter in the absorption process. At elevated amine solution temperatures, the absorption capacity for acidic components may decrease. Therefore, the temperature of the solution supplied to the absorber should be selected according to the gas composition and the type of amine used.

Effect of amine concentration. Increasing the concentration of active amine can enhance the absorption capacity for H_2S and CO_2. At the same time, the concentration should be optimized by considering its effects on solution viscosity, corrosion, foaming, and regeneration energy requirements. Therefore, the amine concentration should be maintained at a technically and economically optimal level.

Effect of solvent flow rate. Increasing the amine solution flow rate enhances the capacity to absorb acidic components while also increasing pumping energy requirements and the amount of heat needed for regeneration. Therefore, the solvent flow rate should be determined according to the initial gas composition and the required degree of purification.

Effect of interfacial contact area. The effective gas–liquid interfacial contact area directly influences the mass transfer rate. Increasing the surface area of the packing enhances mass transfer capacity, while the resulting hydraulic resistance and pressure loss must also be considered. Therefore, absorber design should provide a large effective contact area while maintaining appropriate hydraulic characteristics.

Regeneration of the amine solution. The rich amine solution leaving the absorber is enriched with H_2S and CO_2. To enable solvent reuse, these components must be separated from the solution through regeneration. This process is carried out in a desorber or regeneration column. The rich amine solution is initially heated in a heat

exchanger and then transferred to the regenerator. A reboiler located at the bottom of the column supplies heat to the solution. As a result, H_2S and CO_2 are separated from the amine solution and removed from the top of the column as a vapor–gas mixture. The overhead stream is cooled in a condenser. Part of the resulting condensate may be returned to the column, while the acidic gases are directed to further processing or treatment systems. The regenerated amine is withdrawn from the bottom of the column, cooled through heat exchange, and subsequently pumped back to the absorber. A substantial portion of the energy consumption during regeneration is associated with the reboiler. Therefore, efficient heat exchange between rich and regenerated amine solutions is an important approach to improving the energy efficiency of the process.

Process improvement directions. Based on the literature analysis and the characteristics of the technological process, several principal directions for improving absorber column efficiency can be identified. The first direction involves ensuring uniform gas and liquid distribution in packed absorbers. The application of modern structured packing materials can increase the effective interfacial contact area while optimizing pressure losses. The design of liquid distributors is also essential for achieving uniform flow distribution. The second direction focuses on improving the energy efficiency of the regeneration system. Preheating the rich amine solution using heat recovered from the hot regenerated solution before its introduction into the regenerator reduces the thermal load on the reboiler. Improved heat exchange contributes to reducing the overall energy consumption of the facility. The third direction involves selecting an appropriate amine solution according to technological conditions. In practice, amines such as monoethanolamine (MEA), diethanolamine (DEA), and methyldiethanolamine (MDEA) are commonly used. These solvents differ in their H_2S and CO_2 absorption capacities, selectivity, and regeneration energy requirements. Therefore, solvent selection requires a comprehensive evaluation of gas composition, the required degree of purification, and energy consumption.

The fourth direction involves mathematical modeling of absorber operating conditions and the improvement of automatic control systems. Real-time monitoring and control of gas and liquid flow rates, pressure, temperature, and solution concentration contribute to improving process stability.

CONCLUSIONS AND RECOMMENDATIONS

The theoretical and analytical research examined the fundamental principles of amine absorption technology and the structural characteristics of absorber columns used to remove acidic components, such as H_2S and CO_2, from natural gas.

The absorber column is a key component of the gas–liquid mass transfer process, and its efficiency depends on the packing or tray design, gas and liquid flow rates, pressure, temperature, amine concentration, and effective interfacial contact area. In packed columns, uniform liquid distribution and appropriate gas flow distribution are essential for achieving efficient mass transfer.

The literature analysis demonstrated that domestic researchers have extensively examined the theoretical foundations and structural characteristics of absorbers, while foreign studies have placed particular emphasis on determining mass transfer parameters, evaluating packing efficiency, and developing energy-efficient technologies. Therefore, integrating fundamental theoretical approaches with modern mass transfer and energy efficiency methods is recommended to enhance absorber performance.

The coordinated operation of the absorber and regenerator facilitates deep natural gas purification and efficient utilization of amine solutions. Future improvements in absorber column design should focus on the integrated assessment of mass transfer efficiency, hydraulic resistance, energy consumption, and gas purification performance, supported by mathematical modeling and process automation.

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