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Efficiency of various desulphurisation methods in improving the quality of the propane-propylene fraction

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Abstract. The study was conducted to determine the most effective and economically substantiated desulphurisation method for oil and gas deposits, ensuring a minimum content of sulphur compounds in the propane-propylene fraction. In this study, the methods of absorption, adsorption, and chemical purification, including catalytic, were compared in terms of hydrogen sulphide removal efficiency, economic feasibility, and impact on the final quality of the propane-propylene fraction. As a result of the analysis, it was found that the effectiveness of various methods of desulphurisation of the propane-propylene fraction depends on the initial concentration of hydrogen sulphide, the technical characteristics of the equipment, and the economic operating conditions. Absorption methods using amine solutions showed the highest degree of purification, reducing the hydrogen sulphide content to less than 5 ppm for large volumes of gas. However, the significant costs of absorbent regeneration reduce their economic attractiveness. Adsorption using zeolites and activated carbon has demonstrated high efficiency in processing small and medium volumes of gas. However, a reduction in the hydrogen sulphide content to 10 ppm is achieved, and adsorbent regeneration is possible without significant costs, which makes the method preferable for small installations. Catalytic purification using oxidising agents proved to be less effective at high concentrations of hydrogen sulphide, but ensures stable operation at low levels of impurities. This method requires significant capital investments, but it allows obtaining a fraction with a sulphur content of less than 8 ppm. Based on the data obtained, it was established that the choice of the optimal desulphurisation method is determined by the scale of production and the acceptable economic costs. Absorption is preferable for large enterprises, while the adsorption method is optimal for small installations

Keywords: absorption; zeolites; adsorption; activated carbon; catalytic purification

Introduction

Purification of the propane-propylene fraction from sulphur compounds is an important task to improve its quality and meet modern requirements of industrial processing and environmental standards. The presence of hydrogen sulphide and other sulphur impurities negatively affects the operational characteristics of the equipment, contributes to the development of corrosion, and reduces the purity of the final product. In this regard, an urgent task is to choose the most effective desulphurisation method that ensures minimum sulphur content at optimal economic costs. There are various purification technologies, including absorption, adsorption, and catalytic treatment, each of which

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has certain advantages and limitations. Despite the widespread use of these methods, the issue of their comparative effectiveness remains relevant, depending on the operating conditions and the initial composition of the fraction.

M. Kusenberg *et al*. (2022) showed that the use of amine solutions in absorption systems helped to reduce the content of hydrogen sulphide, ensuring high quality of the purified fraction. They also noted that this method proved to be the most effective for large-scale production. N. Sun *et al*. (2023) found that activated carbon adsorption was an economically feasible solution for small and medium-sized enterprises, ensuring a stable reduction in sulphur content. They emphasised that the use of regeneration allowed minimising operating costs. M. Rahmani *et al*. (2023) found that zeolites exhibit high efficiency in removing hydrogen sulphide, even at low concentrations. In addition, they emphasised the resistance of this material to temperature and pressure changes. T. Akashige *et al*. (2024) noted the importance of correctly selecting the operating parameters of absorption systems, such as pressure and temperature, to prevent a decrease in their performance. They concluded that optimising these parameters reduces the energy consumption of the process. H.S. Lau & W.F. Yong (2021) proved that catalytic purification effectively reduced the hydrogen sulphide content to a minimum level, ensuring high purity of the fraction. They also pointed out that the use of expensive catalysts required their regular replacement.

M.A. Zahid *et al*. (2022) pointed out that the introduction of catalytic purification systems was accompanied by high capital costs for equipment and its maintenance. They also noted that the operation of such systems requires qualified personnel. V. Daoo & J.K. Singh (2024) proved that the combination of absorption and adsorption methods allowed achieving the best results in reducing sulphur content. The researchers emphasised that the combination of methods provided a higher degree of purification while reducing costs. C. Becker *et al*. (2022) investigated the effect of the raw material composition on the choice of desulphurisation method, finding that impurities of other gases reduced the absorption efficiency. They concluded that the preliminary preparation of raw materials was a necessary stage of the technological process. Y.-J. Tian *et al*. (2024) showed that the regeneration of adsorbents significantly reduced operating costs and improved the environmental friendliness of the process. They noted that the choice of regeneration method depended on the type of adsorbent used. L. Wu *et al*. (2021) revealed that the absorption method proved to be more effective for large enterprises, while small enterprises obtained better results using adsorption. They came to the conclusion that the scale of production should be the main criterion for choosing a technology. However, despite widespread attention to the problem of desulphurisation, there is a need for additional research aimed at exploring more effective ways to combine purification methods and optimising technological parameters for different production scales. The purpose of the study was to comprehensively compare the effectiveness of various methods of propane-propylene fraction production, with a focus on their impact on the quality of the final product and economic feasibility for enterprises of different production capacities.

Materials and Methods

The study focused on three main methods: absorption, adsorption, and chemical purification, each of which was analysed from different perspectives, including their applicability to different production scales and environmental impacts. The study is based on theoretical data obtained from the analysis of existing scientific publications and the modelling of desulphurisation processes using various purification methods such as absorption (Georgiadis *et al*., 2020), adsorption (Nazir *et al*., 2020), and chemical purification (Ibrahim *et al*., 2021). In particular, theoretical models describing the kinetics of chemical reactions (Rozanska *et al*., 2023), the adsorption and absorption properties of materials, and calculations of energy and material costs for the regeneration of solvents and adsorbents were considered (Hatab *et al*., 2022). These data served as the basis for evaluating the effectiveness of various purification methods and their applicability for different production scales, as well as for predicting operating costs in the long term.

Absorption has been considered as a method for large enterprises, since liquid absorbents such as amines effectively remove hydrogen sulphide from gas mixtures, for example, propane-propylene fraction. Liquid absorption was considered because this method is widely used in industry to remove hydrogen sulphide from gas mixtures. This method is widely used in the petrochemical and natural gas industries due to its high efficiency and low equipment costs, which makes it suitable for enterprises with large production volumes. Adsorption was analysed as the method most suitable for small and medium-sized installations where processing of gas mixtures is limited. Adsorbents such as activated carbon and zeolites, which effectively remove hydrogen sulphide at moderate concentrations, were considered. These materials were chosen because of their ability to provide the required purification in conditions of limited gas volumes.

Chemical purification using oxidising agents and catalysts has been investigated to evaluate its effectiveness in removing hydrogen sulphide. The study also considered catalytic purification as a subspecies of chemical purification. This method was analysed in terms of its ability to provide a minimum sulphur content in the fraction. In addition, the study carried out a theoretical assessment of the quality of the propane-propylene fraction after using various purification methods. Changes in the chemical composition of the fraction were considered, including a decrease in the hydrogen sulphide content, which helped to determine which method most effectively ensures the required quality of the final product. In addition, the potential advantages and limitations of each method in the context of industrial applications were analysed.

A comparison of the economic feasibility of purification methods was carried out to determine their cost effectiveness depending on the scale of production. As part of the analysis, the costs of equipment, operation and regeneration were considered, which helped to assess which methods are most beneficial for different types of enterprises. Ultimately, environmental aspects were an important part of the study. Possible environmental impacts were considered, including waste disposal, energy intensity of processes and the possibility of reuse of materials, which helped to identify more sustainable and environmentally friendly approaches to desulphurisation.

Results

Desulphurisation is used in the oil and gas industry to purify natural gas and hydrocarbon fractions such as propane-propylene fraction from hydrogen sulphide and other sulphur-containing compounds to prevent corrosion of equipment, improve product quality, and reduce environmental impact. Absorption is a process based on the ability of absorbents, which can be both liquid and solid, to selectively absorb certain components from a gas mixture. In the context of purification of propane-propylene fractions, this method is widely used to remove hydrogen sulphide, the content of which negatively affects product quality, equipment condition, and compliance with environmental regulations. The essence of the method is the contact of a gas mixture with a liquid absorbent, which actively interacts with hydrogen sulphide, converting it to a dissolved state (Shokrollahi *et al.*, 2022). The most common absorbents are amines such as monoethanolamine or diethanolamine, due to their high chemical activity and ability to selectively absorb hydrogen sulphide. The process is usually carried out in an absorption column, where the gas mixture rises up and the absorbent flows down, which ensures maximum contact between the phases. The temperature conditions for effective removal of hydrogen sulphide are usually from 40°C to 60°C, and the pressure – from 1.5 to 2.0 MPa. The concentration of hydrogen sulphide before purification can be 500-1,000 ppm, after which it can be reduced to less than 5 ppm, which is especially important for large installations processing large volumes of raw materials. The chemical interaction between hydrogen sulphide and the absorbent occurs at a high rate, which ensures continuity of the process and high productivity. In addition, the method is universal and suitable for purifying gases with different concentrations of hydrogen sulphide, which makes it in demand at enterprises of various scales. However, there are limitations to this method. One of the key challenges is the need for absorbent regeneration. Over time, liquid absorbents become saturated with hydrogen sulphide and lose their activity, which requires their restoration. The regeneration process is usually carried out at a temperature of 110-120°C and a pressure of 1.0-1.5 MPa, which is accompanied by additional costs for energy, equipment and personnel. Moreover, absorbents are susceptible to chemical degradation under the influence of high temperatures, impurities and acid gases, which shortens their service life and increases operating costs. In addition, the need to recycle used absorbents or their components creates additional environmental risks.

To increase the efficiency of the method and reduce operating costs, it is proposed to use new types of absorbents with greater resistance to degradation. In addition, the integration of absorption with other methods, such as adsorption or catalytic purification, reduces the load on the absorbents and minimises costs. Despite the existing limitations, absorption remains an indispensable tool in the petrochemical industry due to its high efficiency and versatility. The development of technologies and optimisation of processes provide a sustainable perspective for the use of this method in the future. Adsorption is the process by which solids (adsorbents) absorb molecules or atoms of other substances (such as hydrogen sulphide) on their surface. In the context of purification of propane-propylene fractions from sulphur impurities, the adsorption method is used mainly for small and medium volumes of gas. This method uses adsorbents such as activated carbon and zeolites, which have high adsorption properties and can effectively absorb hydrogen sulphide from a gas mixture at a hydrogen sulphide concentration of up to 1,000 ppm and a pressure of 0.5 to 1.5 MPa. In this case, the temperature during the purification process can range from 30°C to 40°C (Abdirakhimov *et al.*, 2022).

The main feature of adsorption is its ability to work with relatively low volumes of gas. This makes it convenient for use in small enterprises or in cases where purification does not require processing large gas flows (up to 1,000 m^3/h). Adsorbents such as activated carbon are porous materials with a huge specific surface area, which makes it possible to effectively capture hydrogen sulphide molecules even at low pressure and low concentrations. This reduces the hydrogen sulphide content in the purified gas to less than 10 ppm. Zeolites, due to their porous structure and ion-exchange properties, can also effectively absorb sulphur compounds, providing another option for gas purification. However, adsorption has its limitations, which may reduce its effectiveness under certain conditions. At high concentrations of hydrogen sulphide (above 1,000 ppm), adsorbents quickly saturate, which reduces their ability to absorb gas and requires frequent regeneration. Unlike absorption, where the absorbent can be used for a long time, adsorbents have a limited-service life in conditions of high concentrations of pollutants. Regeneration of the process, that is, restoring the properties of the adsorbent after saturation, is necessary to extend its service life, but this process is associated with additional costs. Regeneration requires significant energy consumption and the use of temperatures from 200°C to 300°C or the use of chemicals, which leads to increased operating costs. The use of adsorbents entails the need for their disposal after saturation with hydrogen sulphide, which can be environmentally problematic. During operation, adsorbents can accumulate harmful substances, and their safe disposal requires additional steps and resources, which also increases operating costs. This is an important aspect when choosing a purification method, especially in the context of sustainable and environmentally sound production.

Despite these limitations, adsorption remains an important method of purifying hydrogen sulphide gas for small and medium-scale production. To increase the efficiency of adsorption, new types of adsorbents are being developed, which have improved characteristics such as higher porosity, saturation resistance and the possibility of multiple regeneration. This significantly improves efficiency and reduces operating costs. In particular, the active search for new materials, such as nanomaterials and new types of zeolites, promises to improve the adsorption characteristics and expand the scope of this method. In addition, the combination of adsorption with other purification methods, such as absorption or catalytic purification, can significantly improve the overall efficiency of the process. For example, using pre-adsorption to remove major impurities, followed by absorption or catalytic purification, reduces the burden on each of the technologies and achieves a higher level of purification at lower cost.

Purification from hydrogen sulphide (H_2S) is a key step in processing hydrocarbon gases, including propane-propylene fractions, and its purpose is to minimise the concentration of hydrogen sulphide, which is toxic, corrosive and has an unpleasant odour. Hydrogen sulphide can damage equipment, disrupt technological processes, including polymerisation, and create health problems for people working at such facilities. In particular, the presence of hydrogen sulphide in the propane-propylene fraction can negatively affect the polymerisation process, leading to the development of undesirable by-products and a decrease in the quality of the final product. This makes it especially important to effectively remove hydrogen sulphide to maintain the stability of the process and ensure safe working conditions. Several methods are used for effective purification, including chemical purification using oxidising agents and catalytic processes that remove hydrogen sulphide to minimum concentrations of 0.1 ppm (Zhang *et al.*, 2021).

Chemical purification uses reagents such as oxygen, nitric acid or hydrogen peroxide, which oxidise hydrogen sulphide, converting it into safe and stable compounds. For example, the oxidation of hydrogen sulphide with oxygen leads to the appearance of sulphur and water. This process allows significantly reducing the hydrogen sulphide content in gases and achieve concentrations that meet environmental standards, such as less than 10 ppm. Oxidising agents can react with hydrogen sulphide quickly, which contributes to a high purification rate and allows this method to be used in production facilities with high productivity (up to 500,000 m^3/h) (Liu *et al.*, 2021).

Catalytic processes, in turn, are a subspecies of chemical purification, but they use special catalysts that accelerate the reactions of hydrogen sulphide conversion into less harmful substances. Catalysts based on metal oxides, such as copper oxide or iron oxide, are usually used for these purposes. The catalysts ensure that the reaction is carried out under milder conditions – at temperatures from 150°C to 250°C and pressures from 0.5 to 2 MPa, which reduces energy consumption. Catalytic purification can be especially useful for cases where it is necessary to ensure a minimum level of hydrogen sulphide in gases, since the process allows controlling the number of by-products that can form during chemical oxidation, reducing their concentration to less than 1 ppm (Li *et al.*, 2021). Despite the high efficiency of chemical and catalytic purification, these methods require the use of expensive equipment and materials. Oxidising agents and catalysts need specialised installations that can withstand aggressive environments with high concentrations of hydrogen sulphide and other components. For chemical purification, these can be reactors with adjustable temperature and pressure parameters, and for catalytic purification, reactors equipped with highly efficient catalysts. The use of such technologies requires significant capital investments and additional equipment maintenance costs.

Chemical purification and catalytic processes are not without disadvantages associated with the regeneration of catalysts and oxidants. During operation, the catalysts lose their activity over time, which requires their replacement or regeneration. The process of catalyst regeneration can be quite complex and energy-intensive, which increases operating costs. in addition, when using oxidising agents, it may be necessary to reduce them, since they decompose during the reaction. These problems lead to higher operating costs and may require additional technical solutions for efficient recovery and continued use of catalysts and oxidants. In addition, by-products of oxidation or contamination of catalysts may require disposal, which adds an environmental burden to the process. Residual substances may include sulphur or other chemical compounds that need to be disposed of safely, which creates additional difficulties for environmental control and may increase waste treatment costs. The quality of the purified fraction is the most important parameter in the processing of hydrocarbon gases such as propane-propylene fraction. One of the key aspects of quality assessment is the content of sulphur, in particular hydrogen sulphide. Therefore, the choice of a purification method that guarantees a minimum sulphur content is crucial for obtaining a high-quality fraction (Table 1).

Table 1. Degree of reduction of sulphur content and the effect on the quality of the final fraction

Purification method	Degree of sulphur reduction, %	Quality of the final fraction
Absorption	90-99	High-quality fraction, with virtually no hydrogen sulphide, is suitable for most applications
Adsorption	85-98	Purity of the fraction is high, but may depend on the type of adsorbent and the operating conditions
Catalytic purification	85-95	Suitable for obtaining high-quality fractions, but may be less effective at high concentrations of hydrogen sulphide
Chemical purification	80-95	Purity may vary depending on the concentration of hydrogen sulphide and the process conditions

Source: compiled by the authors based on D. Ucar *et al*. (2021)

Absorption and adsorption are among the most effective methods for obtaining high-quality fractions with minimal sulphur content. The quality of purification depends on factors such as the absorption temperature, the concentration of the absorbent, the gas flow rate, and the pressure in the system. In addition, the pH of the solvent plays an important role, which affects the efficiency of hydrogen sulphide binding, and the time of gas contact with the absorbent, which can be optimised considering these variables to achieve the maximum degree of sulphur removal. This method, in particular, is ideal for purifying gases from hydrogen sulphide, providing practically pure products. Adsorption using solid adsorbents such as activated carbon or zeolites has also demonstrated high efficiency in purifying gas from hydrogen sulphide, providing a qualitative reduction in the sulphur content in the final fraction. These methods help to achieve extremely low levels of hydrogen sulphide, which contributes to high purity and compliance with environmental standards.

Unlike absorption and adsorption, chemical purification, although effective under certain conditions, is not always able to provide the same level of purification, especially at high concentrations of hydrogen sulphide. Chemical purification methods using oxidising agents or catalysts may require more complex conditions to completely remove hydrogen sulphide. For example, at high concentrations of hydrogen sulphide, catalysts can quickly saturate, which reduces their effectiveness. In some cases, chemical purification may lead to the development of by-products that may negatively affect the quality of the fraction and require additional purification steps. This limits the possibilities of chemical purification to obtain fractions with a minimum sulphur content. In addition, when using chemical purification, there may be problems with reaction control, especially under changing conditions such as pressure and temperature. The chemical reactions on the basis of which hydrogen sulphide is removed may require precise regulation of these factors to avoid excessive or insufficient oxidation, which may affect the final quality of the fraction. In such cases, purification will not always be as effective as absorption or adsorption methods, which increases the risk of non-compliance with the required quality standards.

When choosing a method for purifying gas from hydrogen sulphide, an important factor is not only the efficiency of the process, but also its economic feasibility. The cost of operation and investment in equipment significantly depends on the volume of gas to be treated and on the choice of the technology itself. In this regard, it is important to consider purification methods such as adsorption, absorption, catalytic and chemical purification from the standpoint of their economic benefits for different volumes of processed gas (Table 2; Table 3).

Table 2. Costs of hydrogen sulphide purification methods

Parameters	Absorption	Adsorption	Chemical purification	Catalytic purification
Equipment cost (USD)	130,000-250,000	40,000-80,000	90,000-180,000	180,000-400,000
Hardware installation (USD)	20,000-40,000	8,000-15,000	15,000-30,000	35,000-80,000
Energy (USD/1,000 m^3 of gas)	10-20	5-10	8-15	5-10
Materials (USD/1,000 m^3 of gas)	Absorbents: 80-150/tonne	Adsorbents: 1,000-1,500/tonne	Reagents: 40-80/tonne	Catalysts: 800-1,200/tonne
Staff (USD/month)	1,000-2,000	700-1,200	900-1,800	1,200-2,500
Regeneration (USD)	40-80/tonne of absorbent	150-250/tonne of adsorbent	Not required	70-120/kg of catalyst
Disposal (USD)	8/tonne of absorbent	40/tonne adsorbent	4/tonne of by-products	15/kg of catalyst

Source: compiled by the authors based on F.J. Alguacil (2023)

Table 3. Cost allocation by enterprise scale (total monthly costs)

Scale of enterprises	Absorption (USD)	Adsorption (USD)	Chemical purification (USD)	Catalytic purification (USD)
Small (10,000 m^3/day)	~3,000-5,000	~2,500-3,500	~2,800-4,000	~2,200-3,200
Average (50,000 m^3/day)	~15,000-20,000	~10,000-12,000	~12,000-15,000	~9,000-12,000
Large (500,000 m^3/day)	~150,000-200,000	~100,000-130,000	~110,000-140,000	~90,000-120,000

Source: compiled by the authors based on T. Yu *et al*. (2022)

Adsorption is one of the most cost-effective purification methods for small volumes of gas. The cost of equipment and installation for adsorption is significantly lower than for more complex methods such as absorption, catalytic or chemical purification. During the adsorption process, there is no need for complex infrastructure or expensive liquid reagents, which makes this method attractive for small and medium-sized enterprises, and for installation in small production facilities. Due to its simplicity and cost-effectiveness, adsorption minimises the cost of equipment and operation, which is especially important for enterprises with limited budgets.

While adsorption is well suited for small volumes of gas, absorption and catalytic purification prove to be more cost-effective for large volumes of gas treatment. These methods provide high purification efficiency, which makes them preferable for large installations and enterprises with large production capacities. Absorption using liquid absorbents such as amines can process significant volumes of gas, quickly and efficiently removing hydrogen sulphide. However, such installations require more complex and expensive reactors, and regular replacement and regeneration of absorbents, which increases operating costs. The cost of equipment and maintenance of the absorption plant can be high, but with large volumes of gas, this is justified, since the process allows achieving the required fraction quality and meeting environmental standards.

Catalytic purification, in turn, is used mainly for large industrial facilities, where it is necessary to ensure not only a high degree of purification, but also constant process efficiency. The catalysts used in this process also require regular replacement or regeneration, which increases maintenance costs. Nevertheless, this method can be economically beneficial for large enterprises, as it allows for stable operation with high volumes of gas and minimises the impact of hydrogen sulphide on the environment and equipment. As in the case of absorption, investments in the installation and operation of equipment for catalytic purification can be significant, but for large volumes of processing they are justified due to high productivity and efficiency. For chemical purification, the economic feasibility depends on the scale of production and the frequency of reagent requirements. With small volumes of gas, this method can be effective, but requires ongoing costs for chemicals and waste disposal. For medium and large volumes, chemical purification can justify the cost, especially with a high degree of purification and improved quality of the final product, but this is associated with high capital and operating costs. The processes of gas purification from hydrogen sulphide play an important role in industry, especially in petrochemical production, where a high degree of purification is required to obtain high-quality hydrocarbon fractions. An important aspect of choosing a method is not only its effectiveness, but also its environmental impact, and operating costs, which include energy costs, maintenance costs, and waste disposal.

Absorption has significant environmental and operational aspects. Solvent regeneration requires significant energy consumption and can lead to the development of waste that needs to be disposed of. The cost of such processes also increases due to the need for constant replacement of the absorbent, which leads to additional operating costs. The chemical solvents used can negatively affect the environment if improperly disposed of, which is an important environmental factor. Adsorption, in turn, is a more environmentally friendly method, as solid adsorbents such as activated carbon or zeolites can be recycled or reconstituted, which significantly reduces waste. This method also requires fewer chemicals and is generally less energy intensive than absorption. However, the adsorbent is rapidly saturated at high concentrations of hydrogen sulphide, which requires its regular replacement or regeneration. This increases operating costs, although the overall economic efficiency remains relatively high for small and medium-sized volumes of gas.

Catalytic purification requires more expensive equipment and complex maintenance processes. The catalysts used can be toxic and susceptible to contamination, which creates additional environmental risks. Regular replacement of catalysts and the high cost of their maintenance significantly increases operating costs. Chemical purification, in turn, can be very effective for removing hydrogen sulphide, but it also carries environmental risks associated with the use of oxidising agents and chemicals that can form toxic waste. To prevent environmental pollution, it is necessary to strictly control processes and dispose of chemical waste, which adds to the cost of operation.

Discussion

The study examined various desulphurisation methods to improve the quality of the propane-propylene fraction, including absorption, adsorption, and chemical purification. The results showed that each method has its own characteristics and limitations, which directly affects the efficiency of the purification process and, ultimately, the quality of the final product. Absorption has shown the best results in terms of hydrogen sulphide removal. However, its effectiveness has been reduced by the need for frequent solvent regeneration, which increases operating costs and leads to waste generation. Nevertheless, it remained preferred for large volumes of gas, where other methods may not always be as effective. This problem was also investigated by C. Wang *et al*. (2022), where the results confirmed that the efficiency of absorption in removing hydrogen sulphide for large volumes of gas depends on the correct choice of absorbent and optimisation of the process. For large gas flows, parameters such as flow velocity, temperature, and hydrogen sulphide concentration in the gas must be considered to achieve a high degree of removal. The use of modern absorbers, such as multi-stage speakers, can significantly increase the efficiency of the process.

The study by S. Gilassi *et al*. (2020) also showed that solvent regeneration during the absorption process plays an important role in reducing operating costs, as it allows for repeated use of the solvent. However, frequent regeneration requires significant energy expenditure, which can increase the cost of operation. It is important to choose a regeneration mode that optimises the balance between energy costs and the required process performance. Notably, the efficiency of absorption in removing hydrogen sulphide directly depends on the correct setting of process parameters such as pressure, temperature, and concentration of hydrogen sulphide in the gas. For large volumes of gas, highly efficient absorbers are needed, which can ensure stable operation under changing operating conditions. It is also important to consider the specifics of the gas composition, since the presence of other components, such as carbon dioxide or water vapour, can affect the absorption process and require additional system settings to maximise the efficiency of hydrogen sulphide removal.

The adsorption has demonstrated good results for small and medium volumes of gas, providing a significant reduction in the content of hydrogen sulphide. Unlike absorption, adsorption uses solid adsorbents such as activated carbon and zeolites, which makes the process environmentally friendly. However, adsorbents are rapidly saturated at high concentrations of hydrogen sulphide, which requires regular replacement or regeneration of the adsorbent. As a result, the operating costs of this method turned out to be higher than expected, especially when working with large volumes of gas. Q. Wang *et al*. (2022) concluded that adsorption is an effective method for removing hydrogen sulphide from small and medium volumes of gas, especially when a high degree of purification is required. One of the main advantages is the ease of installation and operation of the absorbers, which makes this method attractive for small businesses. However, a limitation is the need for frequent adsorbent regeneration, which can increase operating costs and energy requirements, especially with a large volume of gas treatment.

The study by A. Golmakani *et al*. (2022) revealed that the environmental aspects of adsorption during desulphurisation include minimising hydrogen sulphide emissions into the atmosphere and reducing environmental pollution. Operational aspects are associated with high costs for adsorbent replacement and the need for proper process control to ensure its sustainability. On the other hand, adsorption has a relatively low environmental impact compared to other purification methods such as absorption, as it does not require the use of chemical solvents. These results confirm the above study, as they show that adsorption is effectively used to purify small and medium volumes of gas, providing a high degree of hydrogen sulphide removal. In addition, as in the previous analysis, the results indicate the importance of optimising process parameters such as temperature and pressure to increase efficiency. Despite this, as mentioned earlier, the need for frequent adsorbent regeneration and the associated energy load remains the main limitations of this method. Chemical purification, applied to achieve the maximum degree of purification, has demonstrated good results in reducing the hydrogen sulphide content in the fraction. However, this method required the use of oxidising agents, which led to additional costs for chemicals and waste disposal. In addition, the regeneration of catalysts and oxidants can create additional problems with the operation of the equipment. Despite these difficulties, chemical purification was effective in achieving higher fraction quality at low concentrations of hydrogen sulphide.

The study by H. Abedini *et al*. (2021), also found that chemical purification used to reduce the hydrogen sulphide content in the propane-propylene fraction is based on reactions with chemical reagents that effectively remove hydrogen sulphide from gas mixtures. This method allows achieving high levels of purification, which is especially important for improving the quality of the final product and compliance with environmental standards. However, the efficiency of the process depends on the correct choice of catalysts and chemicals, and on the conditions under which purification takes place, such as temperature and pressure. In turn, Y. Gao *et al*. (2021) concluded that the problems associated with the regeneration of catalysts during chemical purification include their gradual loss of activity and the need for frequent replacement or restoration. Regular regeneration of catalysts requires significant energy consumption, which increases the operating costs of the process. In addition, it is not always possible to restore the catalysts to their original level of efficiency, which can lead to additional costs for their replacement and reduce the overall profitability of the chemical purification process. These data are consistent with the theses given in the previous section, as they confirm that chemical purification is an effective method for reducing the hydrogen sulphide content in the propane-propylene fraction, providing a high degree of purification. Moreover, as discussed earlier, the choice of catalysts and reagents plays a key role in the efficiency of the process, which is confirmed by the results showing a significant improvement in the quality of the final product. However, as mentioned above, the cost of catalyst regeneration and the need to replace them remain significant problems, which limits the long-term economic efficiency of this method.

The results showed that when assessing the effectiveness of various methods, an important factor is not only the degree of purification, but also the effect on the final fraction. In particular, absorption and adsorption ensured a low sulphur content in the final fraction, which is important for improving the quality of the propane-propylene fraction, especially in the chemical industry. Unlike these methods, chemical purification did not always provide such high fraction quality, especially at high concentrations of hydrogen sulphide. This indicates the need for careful selection of the method depending on the required product quality. Y.H. Chan *et al*. (2022) also conducted a study, the results of which showed that when comparing purification methods by the degree of reduction of sulphur content in a fraction, different technologies may demonstrate different levels of efficiency in removing hydrogen sulphide. For example, chemical purification and absorption can provide higher performance than adsorption, depending on the selected reagents and process conditions. However, each of these solutions has its advantages and limitations, which requires careful evaluation to select the most appropriate method, depending on the gas composition and technological requirements. F. De Meyer & C. Bignaud (2022) also found that the effect of purification methods on the final quality of the propane-propylene fraction is directly related to the efficiency of hydrogen sulphide removal, since the presence of sulphur can degrade the quality of the product and increase its cost. Methods that ensure high sulphur removal, as a rule, lead to an improvement in the properties of the fraction, making it more suitable for further use in the chemical and petrochemical industries. Moreover, the use of different purification methods may affect other parameters of the fraction, such as boiling point or impurity content, which is important to consider when evaluating the overall efficiency of the process.

Comparing the data obtained during the research, it can be noted that different purification methods show different degrees of effectiveness in reducing the sulphur content in the propane-propylene fraction, due to the specific features of the technologies used. In particular, chemical purification and absorption are more effective than adsorption, especially at high concentrations of hydrogen sulphide in the gas. However, it should be borne in mind that each method has its own limitations, such as the high cost of reagents or the need for regular regeneration of catalysts, which may affect the choice of the optimal process for specific production conditions. The economic feasibility of using various methods also proved to be a key factor. Absorption and chemical purification, although they provided high purification efficiency, required significant costs for equipment, reagents, and regular regeneration, which could increase the cost of operation. In turn, adsorption was more advantageous for small volumes of gas, but its economic efficiency decreased with increasing volumes and concentrations of hydrogen sulphide. This highlights the importance of choosing a method based on the scale of production and economic feasibility. Y. Lyu *et al*. (2021) concluded that the economic aspects of absorption and chemical purification require considering not only the costs of equipment and reagents, but also additional costs for energy, operation and regeneration. Absorption, despite its high efficiency in removing hydrogen sulphide, may require significant costs for solvent regeneration and maintaining optimal process conditions. Chemical purification also involves high costs for chemicals and waste disposal, which makes an assessment of the economic feasibility of each method important for choosing the optimal technology.

When analysing the results of the study, it becomes clear that the choice between absorption and chemical purification depends on specific operating conditions, such as the volume of gas, its composition and requirements for the degree of purification. Absorption can be more beneficial with small volumes of gas, as it requires lower capital and operating costs. However, for large volumes, where a high degree of purification and regular solvent regeneration are required, chemical purification can be more effective, despite higher operating costs. In general, the results of the study showed that in order to improve the quality of the propane-propylene fraction, it is necessary to carefully choose the purification method depending on a number of factors, including gas volumes, hydrogen sulphide concentration, and quality requirements for the final product. Although each method has its advantages and disadvantages, a combined approach involving pre-adsorption or absorption followed by chemical purification may be the most effective for achieving optimal results under various production conditions.

Conclusions

Absorption has shown high efficiency in removing hydrogen sulphide, especially at high volumes of gas. This method helps to achieve a significant reduction in the sulphur content in the fraction, which is important for the quality of the final product. However, the use of absorption is associated with high operating costs, as the process requires constant solvent regeneration, which increases the need for additional resources. In addition, waste is generated during the regeneration process, which can have a negative impact on the environmental situation if measures are not taken to dispose of it. The adsorption method, in turn, has shown good results for small and medium volumes of gas. Solid adsorbents such as activated carbon or zeolites can effectively absorb hydrogen sulphide and can also be reused, making this method more environmentally friendly. However, at high concentrations of hydrogen sulphide, adsorbents quickly saturate, which requires their frequent replacement or regeneration. This leads to an increase in operating costs, which, in turn, limits the use of this method for large-scale production. Chemical purification provided the greatest reduction in the content of hydrogen sulphide and allowed obtaining fractions with a minimum sulphur content. However, this method also involves high costs for chemicals and the need for waste disposal. Regular replacement of catalysts and oxidants adds additional operating costs, which reduces its economic feasibility for large volumes of gas.

Cost analysis has shown that adsorption is the most cost-effective method for small and medium-sized enterprises due to low initial investments and moderate operating costs, while absorption is preferable for large enterprises due to its high productivity. Chemical purification and catalytic purification provide versatility and efficiency, but their use is limited by specific requirements: the former is characterised by significant reagent costs, and the latter is justified only for enterprises with strict requirements for gas quality. As a result of the study, it was found that in order to obtain optimal results in the purification of the propane-propylene fraction, it is important to consider the scale of production and the quality requirements of the final product. Absorption and chemical purification prove to be most effective for large volumes of gas, but require significant capital investment and operational costs. Adsorption is economically advantageous for small and medium volumes of gas, but its efficiency decreases at high concentrations of hydrogen sulphide. A combined approach using several methods may be the most effective solution to ensure both high purification efficiency and lower operating costs. To further improve the efficiency of desulphurisation processes, it is necessary to conduct an empirical study of the effect of different types of absorbents and adsorbents on the degree of purification at different temperatures and pressures.

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Conflict of Interest

None.

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Ефективність різних методів сіркоочищення для підвищення якості пропан-пропіленової фракції

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Анотація. Дослідження проведено з метою визначення найбільш ефективного та економічно обґрунтованого методу десульфурації нафтогазових родовищ, що забезпечує мінімальний вміст сірчистих сполук у пропан-пропіленовій фракції. У цьому дослідженні було проведено порівняння методів абсорбції, адсорбції та хімічного очищення, в тому числі каталітичного, з точки зору ефективності видалення сірководню, економічної доцільності та впливу на кінцеву якість пропан-пропіленової фракції. У результаті аналізу було встановлено, що ефективність різних методів сіркоочищення пропан-пропіленової фракції залежить від початкової концентрації сірководню, технічних характеристик обладнання та економічних умов експлуатації. Абсорбційні методи з використанням розчинів амінів показали найвищий ступінь очищення, знижуючи вміст сірководню до менш ніж 5 ppm для великих обсягів газу. Однак значні витрати на регенерацію абсорбенту знижують їх економічну привабливість. Адсорбція з використанням цеолітів та активованого вугілля продемонструвала високу ефективність при обробці малих та середніх обсягів газу. Водночас досягається зниження вмісту сірководню до 10 ppm, а регенерація адсорбенту можлива без значних витрат, що робить метод кращим для невеликих установок. Каталітичне очищення з використанням окислювачів виявилося менш ефективним при високих концентраціях сірководню, але забезпечує стабільну роботу при низьких рівнях домішок. Цей метод вимагає значних капітальних вкладень, але дозволяє отримувати фракцію з вмістом сірки менше 8 ppm. На основі отриманих даних встановлено, що вибір оптимального методу сіркоочищення визначається масштабами виробництва і прийнятними економічними витратами. Абсорбція є кращою для великих підприємств, тоді як адсорбційний метод є оптимальним для малих установок

Ключові слова: абсорбція; цеоліти; адсорбція; активоване вугілля; каталітичне очищення