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INVESTIGATION OF THERMAL AND CATALYTIC PURIFICATION OF OIL REFINING GASES

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ARTICLE INFO	ABSTRACT
<p>Article history: Received:2025-04-30 Received in revised form:2025-05-21 Accepted:2025-06-14 Available online:2025-12-25</p>	<p>Oil refining and petrochemical industries are considered to be one of the most strategic sectors of the modern economy, but also one of the main sources of environmental pollution. During the processing of raw materials and the production of various products in these enterprises, large volumes of harmful gases are released into the atmosphere. Problems related to the utilization and purification of oil refining gases are very relevant in modern times. In this regard, thermal and catalytic methods are the most widely used and promising technologies for the decomposition and neutralization of harmful gases emitted into the atmosphere.</p>
<p>Keywords: gases; thermal; catalytic purification; Claus process; sulfur compounds</p>	<p>The article examines the methods of thermal and catalytic purification of gases resulting from technological processes in the oil refining and petrochemical industries. The ecological impacts of sulfur compounds, carbon oxides and nitrogen oxides contained in these gases are analyzed, and the main thermal and catalytic technologies used to minimize them are comparatively evaluated. The advantages and disadvantages of integrated purification schemes used in modern industrial practice are discussed. Based on the analysis, it was concluded that catalytic methods are relatively energy-efficient, while thermal methods are also a suitable technological solution for the purification of high-concentration gas streams.</p>

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1. INTRODUCTION

The oil refining and petrochemical industry is economically very important, but it is considered one of the industries that creates major problems from an ecological point of view. Gases of various compositions are formed in the primary and secondary oil refining processes, and their release into the atmosphere without purification leads to the emergence of ecological problems and imbalances [1]. The main polluting components of these gases are hydrogen sulfide, sulfur dioxide, carbon monoxide, carbon dioxide and nitrogen oxides. These substances accumulate in the atmosphere and thus lead to the formation of dangerous conditions for human health, the formation of acid rain, and climate change [2]. It is for this reason that the main priority in the entire world industry is currently the purification of gases to be released into the atmosphere and the creation of environmentally friendly processes.

The main purpose of the article is to analyze these methods in terms of scientific basis, application possibilities and efficiency. The object of the article is the process of refining sulfuric acid gases generated in the oil industry using a thermal gas burner, a Claus sulfur recovery unit, and a waste gas cleaning unit. The scheme of the experimental setup is given in Fig.1.

2. EXPERIMENTAL PART

Gas in oil refining processes are mainly generated in atmospheric-vacuum, catalytic cracking, hydrocracking and hydrotreating units. Their composition varies depending on the sulfur content of the feedstock and the process conditions [4]. H₂S, which is formed in the processes, is the main hazardous substance. Sulfur oxides formed from its oxidation react with water vapor in the atmosphere and cause the formation of acid rain [5].

As a result of the Claus process, H₂S is utilized in the form of harmless elemental sulfur [6].

The experimental part was carried out on the basis of modeling the operating mode of industrial facilities and technological analysis based on literature data. For calculations, a stationary operating mode and a constant raw material composition accepted in industrial practice were assumed. The main devices of the technological scheme adopted for the study are:

1. Thermal gas incinerator-partial oxidation of H₂S
2. Claus catalytic reactors-catalytic recovery of sulfur
3. Condensers-separation of the resulting sulfur in liquid form
4. Waste gas cleaning unit-capture of SO₂, COS, CS₂ and H₂S by reduction and absorption

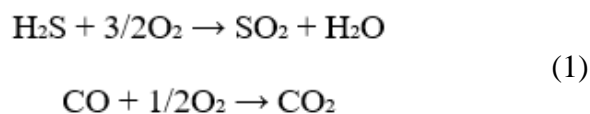
The parameters affecting the course of the process are temperature and pressure, H₂S/O₂ stoichiometric ratio, type of catalyst, its activity, and the effectiveness of the reduction medium at the waste gas cleaning stage. If the necessary ratio between the parameters is maintained, along with high sulfur yield, less damage to the environment will be caused.

In the thermal stage, the temperature is assumed to be in the range of 1000-1300 °C. As a result of burning gases at 900–1200 °C, the effect of harmful components is reduced [7]. As in all chemical processes, the application of a catalyst in this process also creates conditions for reducing the operating temperature. In the catalytic stage, the temperature is assumed to be in the range of 200-350 °C. The operating pressure of the process is 0,1-0,25 MPa. The amount of H₂S in 1m³ sour gas is 60-75%. The stoichiometric ratio of oxygen is assumed to be 1:3 mol O₂:H₂S.

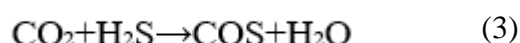
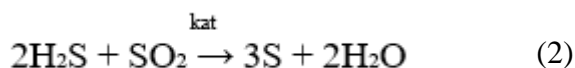
Thermal treatment methods are based on the oxidation of gases at high temperatures. These processes are usually carried out with thermal oxidizers or thermal reactors. The main advantage of these methods is that they do not require a catalyst and are suitable for the treatment of high-concentration gas streams, but the lack of energy savings and the formation of nitrogen oxides limit their use [8]. Catalytic purification methods are based on the oxidation of gases at low temperatures in the presence of catalysts.

The experimental study was conducted on the basis of modeling the processes of thermal and catalytic purification of petroleum refinery gases. The study was based on typical technological regimes adopted at industrial enterprises. In the model experiment, attention was paid to the processes of first thermal conversion of H₂S and then sulfur recovery at the catalytic stage [3].

Thermal stage:



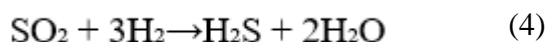
Catalytic stage:



Side reactions:

After the sulfur removal process, small amounts of H₂S and SO₂ remain in the residual gases. These gases are fed to the catalytic residual gas treatment process for further purification. The main reaction at this stage is:

After that, the H₂S is sent back to the Claus unit [9]. This stage allows to increase the total sulfur



recovery efficiency to 99.9%.

Catalytic treatment is usually carried out in the temperature range of 200-350 °C, which creates the basis for reducing energy consumption [10]. Platinum, palladium and vanadium-based catalysts provide very good oxidation of sour gases [6]. Although the advantages of catalytic methods are their high selectivity, energy saving and impact on improving environmental performance, the loss of catalyst activity and the possibility of poisoning should be taken into account when applying these methods [9]. Literature studies prove that thermal methods are more suitable for gases with high concentrations and variable composition. Catalytic methods are distinguished by their high conversion rate and energy efficiency at low temperatures [11]. The advantages of both methods lead to their application in a combined version, and their integrated use in the modern oil refining industry gives optimal results from an ecological and economic point of view [12].

According to the results of the modeling, the oxidation rate of H₂S in the thermal reactor at a temperature range of 1100–1300 °C is 65–70%. At this stage, part of the hydrogen sulfide reacts with oxygen and turns into sulfur dioxide, while the rest forms the stoichiometric ratio required for the Claus reaction. Although the high temperature ensures the effective decomposition of H₂S, at the same time, the formation of by-products such as COS and CS₂ has been observed. Experiments show that increasing the temperature above 1300 °C in the thermal stage increases the intensity of side reactions, which creates the need for additional purification in subsequent stages. Therefore, the selection of the optimal temperature regime directly affects the efficiency of the process. In the catalytic stage, a decrease in temperature below normal weakens the kinetics of the Claus reaction, while high temperatures lead to sulfur re-evaporation and catalyst deactivation. This is considered undesirable in terms of process sustainability.

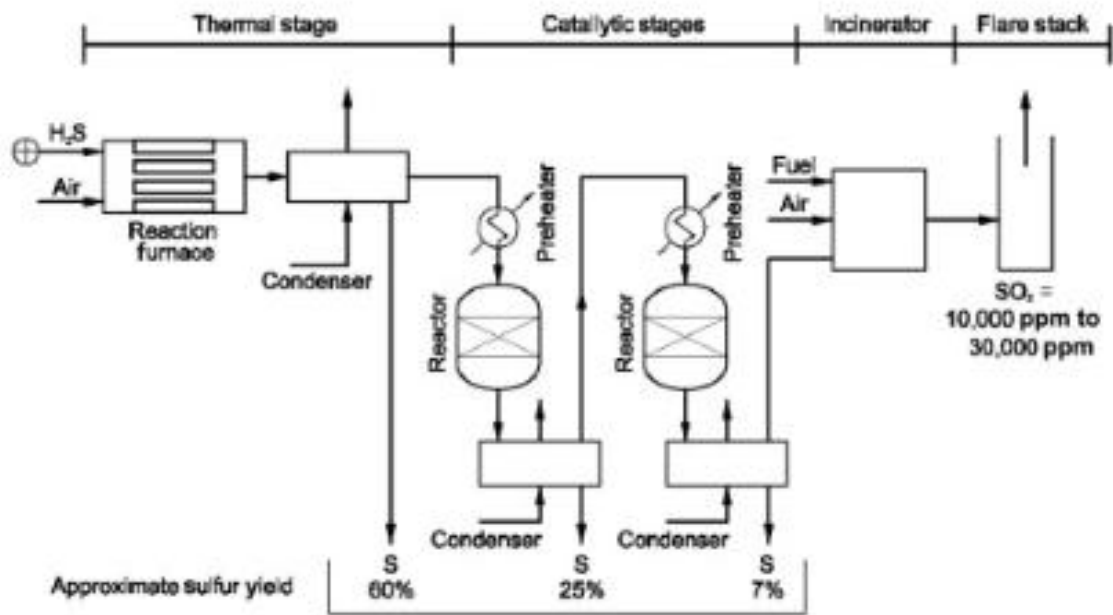


Fig. 1 Technological scheme of the plant

The modeling results of the residual gas purification unit showed that the SO₂, COS and CS₂ compounds present in the gases leaving the Claus unit are reduced with hydrogen and converted back to the H₂S form. At this stage, the converted H₂S is directed to the absorption system and returned to the process.

According to the modeling results of the catalytic stage, the intensity of the Claus reaction has significantly increased with the participation of aluminum-oxide and titanium-oxide-based catalysts. As a result of the process carried out in the temperature range of 220–340 °C, an additional 25–30% sulfur recovery was ensured.

In general, as a result of the joint action of the thermal and catalytic stages, the elemental sulfur recovery efficiency varied in the range of 92–96%. This indicator corresponds to the normative limits adopted for modern industrial Claus units. As a result of the application of the residual gas purification stage, the total sulfur recovery efficiency was increased to 99,8–99,9%. The amount of sulfur compounds in the gases released into the atmosphere was below 10 ppm, which fully complies with environmental standards. Without a residual gas cleaning stage, it is impossible for the Claus unit to meet modern environmental requirements. As a result of the research conducted in the article, it was determined that the treatment of petroleum refinery gases by thermal and catalytic methods plays an important role in protecting the atmosphere.

Thermal treatment provides a reliable technological solution for highly concentrated gas streams, while catalytic methods are considered more energy-efficient and environmentally superior. The application of thermal-catalytic integrated systems allows minimizing harmful emissions in the petroleum refining industry and ensuring compliance with international environmental standards. The application of integrated thermal-catalytic treatment technologies allows reducing atmospheric emissions in the petroleum refining and petrochemical industries and ensuring compliance with international environmental standards.

3. Conclusion

- The processes of thermal and catalytic purification of petroleum refinery gases were investigated based on a model experimental approach.
- The calculations and modeling results showed that in the thermal gas combustion stage, the degree of oxidation of hydrogen sulfide in the temperature range of 1150–1300 °C varies between 66,4–70,2%, and this stage ensures the formation of the stoichiometric ratio necessary for the Claus reaction.
- As a result of the application of aluminum oxide and titanium oxide-based catalysts in the catalytic stage, additional sulfur recovery was 28,6-30,4%. As a result of the combined action of the thermal and catalytic stages, the total recovery efficiency of elemental sulfur was determined at the level of 94,7%.
- As a result of the application of the residual gas purification unit, the conversion rates of SO₂, COS and CS₂ compounds were 99,1%, 98,6% and 97,9%, respectively. After this stage, the concentration of sulfur-containing compounds in the gases released into the atmosphere was reduced to 8–9 ppm.
- Overall, the total sulfur recovery efficiency was increased to 99,85% due to the integration of the residual gas cleaning stage. The results obtained show that without this stage, the emission level is 180-220 ppm and does not meet modern environmental standards.

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