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Investigation of Sweetening Process of Sour Gas with Using Zinc Oxide Nano-Fluid in Different Magnetic Fields to Optimization of Energy

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Abstract

It is evacuated and after millions of years, it has become coal, oil and natural gas. These types of fossil fuels mentioned, at different times and in line with the level of progress in technical knowledge and the ability of humans to explore, exploit, and use, have had a different level of application in everyday life, work, and industry. In this paper, the mechanism for absorption of sulfur from sour gas by carbon nanotube in a packed bed under a magnetic field is considered. The minimum amount of hydrogen sulfide in the output stream is selected as the aim of the experiments and related conditions as optimal operating conditions. The magnetic field increases the molecular movement and, as a result, the process temperature is somewhat increased and affects the movement of carbon nanotubes in the nano-fluid layer as well as nano-carbon pipes that are dissolved separately. An effective factor for determining the mass flow rate and mass transfer coefficient is determined to indicate the effect of the magnetic field. Finally, the experimental data are presented and compared with the results of the model, and the experimental results have a fairly good fit with theoretical results. The effect of temperature on the increase in the amount of mass transfer appears to be greater than the observed amount due to the gas flow rate. Results show, increasing the temperature from 20°C to 30°C increases the average mass flow rate by about 35.2%.

Keywords

Sweetening Process, Sour Gas, Bed Porosity, Carbon Nanotube, Sulfur

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1. Introduction

The different processes are used to convert natural gas to different products. At the moment, sulfur is considered as an impurity in fossil fuels [1]. By burning fuels, sulfur is released in the form of sulfur dioxide, which is one of the air pollutants that cause respiratory problems and acid rain. The environmental regulations limit emissions of sulfur dioxide and force fuel processors to remove sulfur from fuels and effluent gases. In 2017, the cost of removing sulfur from natural gas and crude oil in the United States was about 1.25$ [2]. In natural gas, sulfur is essentially hydrogen sulfide, while in crude oil, there are sulfur organic compounds. The combination of hydrogen and sulfur can produce the hydrogen sulfide. In both of these situations, the highly toxic and corrosive gas of hydrogen sulfide should be converted into sulfur and removed from the system for sale or disposal. The hydrogen sulfide is a weak acid, which, when dissolved in water or sludge, enters the following two steps:

$$H_2S \leftrightarrow H^+ + HS^- \tag{1}$$

$$HS^- + OH \leftrightarrow S^{--} + H_2O \tag{2}$$

The two above steps can be run back and forth, depending on the pH value.

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1.1. Energy and Demand

Generally speaking, energy is considered as one of the most basic human needs today. The energy is a vital need of the industry, food production and agricultural production [3]. Therefore, human need for energy is inevitable, while a large percentage of the world's total energy comes from fossil fuels, the use of which inevitably causes harm to human health on the one hand and damage to equipment and facilities the industries that make use of them. This is not a bad point, but a transitory reference to fossil fuels and the history of their formation [4]. The fossil fuels are called to fuels, which are derived from fossils. Fossil fuels are divided into three main types, including coal and oil and natural gas. Each three types, hundred thousand years ago, even before the advent of the dinosaurs, began to form, the period in which these fuels began to form is said the term "Ferro carbon", that is mean carboniferous, that have been part of the Paleozoic era [5]. Carboniferous takes its name from carbon, the most important element of coal and other fossil fuels. The reason they call them fossil fuels is that at that time the earth was full of swamps cluttered with huge trees and ferns and other leafy plants, and as trees and plants drowned deep into the ocean, they were dipped and gradually buried, and the layer a sponge called Pitt was formed. After hundreds of years the peat was covered with sand, clay, and other minerals. Then these miners became over time a sedimentary rock, as more layers accumulate on each other, their weight is also greater. It puts pressure on the pit, and the pit layer is squeezed and compressed to get its water [6]. It is evacuated and after millions of years, it has become coal, oil and natural gas. These types of fossil fuels mentioned, at different times and in line with the level of progress in technical knowledge and the ability of humans to explore, exploit, and use, have had a different level of application in everyday life, work, and industry. But it is obvious that today the use of oil and gas is far more extensive and wider than coal [7].

1.2. Importance and Necessity of Research

The presence of hydrogen sulfide gas in many currents and processes, especially gas flows, is undesirable [8]. So, the eliminating this gas is one of the important issues in various systems. The hydrogen sulfide and sulfur compounds at temperatures and pressures used in oil and gas exploitation systems are almost stable gas, although in the presence of strong oxidizers such as oxygen and iron, it can convert to elemental sulfur, which is usually the phenomenon in the lines high-pressure gas pipe or storage installation occurs [9]. The sulfur compounds at concentrations higher than 80% are also present in some streams of gas from the refinery, and since the gas is acidic and easily soluble in water at various temperatures and pressures, acidic electrolytic solutions form, which are highly corrosive to Metals and alloys. The corrosion of hydrogen sulfide gas is essentially electrochemical [10]. The reaction between hydrogen and iron sulfide causes the formation of a black iron sulfide film, the amount of which is formed, plays a very important role in determining the corrosion rate [11].

2. Materials and Methods

2.1. Components and Methods

Sour gases containing different amounts of hydrogen sulfide are fed into the catalytic bed. Two 20-liter pressure vessels containing sour gas can be connected to the test line. Nevertheless, both feeding tanks cannot be used simultaneously. The steel and stainless steel tank, which is 8 cm in diameter and 60 cm in length, are used as the main ingredient for sweetening. The 10 cm below and 10 cm above the inner tank is without packing, containing a distributor and holder. At 40 centimeters, the effective volume of the balls (2.5 centimeters in diameter) is used as packing, as well as two mesh panels for separating the reactor tank into three sections. The gas feed is entered at the speed above the minimum amount of liquid flow, through the distributor and downstream of the reactor. A circular polygonal sheet of polyvinyl chloride with 2 mm holes is used as a gas distributor. The one liter per minute of nano-fluid containing 3%wt. carbon nanotubes with a diameter of about 50 nm is introduced into the reactor tank from the top of the reservoir and through the flow distributor. The electric current flows in a circular coil around the reservoir to generate the magnetic field and the effect of the movement of carbon nanotubes. A 1.1 mm coil with copper wire, with 100 coils approximately 30 cm, is wrapped around a stainless steel tank at a distance of 0.5cm from the outer wall of the reservoir. There is also an electric heater with 100 watts of power in the inlet gas path. The inlet pressure is measured with an electric barometer located up and down the valve. The process temperature in the reservoir is controlled by the temperature of the gas flow and the heat dissipation is ignored because the stainless steel tank is insulated. A 0.02cm mesh polymeric plate is placed on top of the tank as a retainer to permit the entry of the refined gas stream. The relation 3 shows the composition of hydrogen sulfide with oxygen, in which water and sulfur are produced.

$$H_2S + 1/2O_2 \rightarrow 1/xS_x + H_2O \qquad (3)$$

The controlling and measuring equipment is designed to evaluate the operating pressure, operating temperature and flow fluctuations in the flow lines. The stack is made of stainless steel 316 and all valves, pipes and equipment are resistant to corrosion. In addition, the general shape of the gas flow with an extra tubing branch for sample collection and analysis is provided. The gas chromatography is used to determine the amount of sulfur in the outlet and the internal flow. Since long-lived hydrogen sulfide gas and high concentrations are poisonous, another 10 liter polyvinyl chloride collection tank is used to store the liquid gas after the passage of the water cooling coil. A spiral tube that has passed through a refueling coil has been used as a condenser to separate discharging gas from the reactor into gas condensate. There is a one way valve on this line to prevent the flow back to the reactor. Also, a nano-fluid containing hydrogen sulfide is placed in a storage tank at the bottom of the laboratory setup and collected there.

The ε , which is the porosity of the bed. The porosity changes with the number of balls in the packing section. The relationship 4 shows the porosity of the bed. In this regard, the order of V_{nb} is the volume of balls of the packing part and V is equal to the volume of the packing portion of the bed.

$$\varepsilon = 1 - V_{nb} / V \tag{4}$$

Water is used to increase the amount of hydrogen sulfide absorbed into the nano fluid. 3%wt. of carbon nanotubes are combined in of pure water for a period of 180 minutes and a power of 4000 watts in ultrasonic. This time is considered for the duration of carbon dioxide tubes in pure water. This stage is an exothermic process. At this point, water helps oxidation of hydrogen sulfide and also increases the capacity of carbon nanotubes to absorb hydrogen sulfide. The relationships 5, 6, 7, 8 and 9 show the related mechanisms in the absorption of hydrogen sulfide.

$$H_2S(g) \rightarrow H_2S(aq) \tag{5}$$

$$H_2S(aq) \rightarrow H_2S(aq - abs.) \tag{6}$$

$$H_2S(aq - abs.) \rightarrow HS^-(ads.) + H^+ \tag{7}$$

$$HS^-(ads.) + O(ads.) \rightarrow S(ads.) + OH^- \tag{8}$$

$$HS^-(ads.) + 3O(ads.) \rightarrow SO_2(ads.) + OH^- \tag{9}$$

After absorbing hydrogen sulfide in the carbon nanotube, the output gas temperature is relatively high. Also, the temperature increase with magnetic fields is also achieved. Due to some safety constraints, lower feed temperatures of less than 40 centimeters, in addition to the magnetic field, are used. In this study, the basic parameters of the performance of a packed bed, experimentally and theoretically, have been evaluated.

2.2. Mathematical Modeling

In the quiet flow, with only sticky tensile forces, the Reynolds number is less than 20, and experimental data are obtained for the friction coefficient of fluid flow to the bed using the Kozeny-Carman equation, which is the relation 10 [1 and 7].

$$f_b = \frac{150(1-\varepsilon)}{N_{\mathrm{Re},p}\varphi_s} \tag{10}$$

Note: According to the manual (guidebook) for chemical engineering, the 150 coefficient is originally presented by Carman for a quiet flow mode of 180. Later, the Ergun suggested a better value of 150 when it had particles of diameter greater than 150 micrometers [2]. Also, in the turbulent stream where inertial forces are dominant (Reynolds number greater than 1000), the experimental results may be obtained in reverse, according to the Blake Plummer equation, which is the equation 11 [2 and 7].

$$f_b = 1.75 \tag{11}$$

The $N_{\mathrm{Re},p}$ can be defined as 12 as follows:

$$N_{\mathrm{Re},p} = \frac{\rho V_o D_p}{\mu} \tag{12}$$

The drop in the flow of a fluid in a turbulent flow of the bed can be defined quantitatively in the definition of the friction coefficient of the sub frame fp and a partial Reynolds number in relation 13 [5 and 11].

$$\Delta P = \frac{f_b V_0^2 L(1-\varepsilon)}{g_c \varphi_s D_p \varepsilon^3} \tag{13}$$

ΔP = Pressure drop in the liquid bed

L = Depth or length of the bed

g_c = Conversion Constant

D_p = particle diameter

ρ = fluid density

ε = Substrate or porosity

Vo = apparent fluid velocity

μ = viscosity or fluid adherence

φ_s = sphericity

The apparent velocity of the fluid in which the fluid moves in a moving bed is first defined and calculated as the minimum fluid velocity (V_{om}). In other words, it is first necessary to calculate the fluidity velocity and then evaluate at a faster rate than this process speedy.

$$V_0 = \frac{g(\rho_p - \rho)\varepsilon^3 \varphi_s^2 D_p^2}{150(1-\varepsilon)\mu} \quad (14)$$

Changes in the porosity of the bed are evaluated by measuring the drop in pressure and the minimum speed. Therefore, the experiments are carried out over the minimum speed, and the pressure drop between the top and bottom of the fluid bed is considered. The total mass transfer from gas to nano-fluid is equal to the pure amount of hydrogen sulfide between the inlet and outlet gas flow. Since L/D = 5, the mass transfer that changes along the bed is desired and changes in the direction of the radius of the bed are ignored. The equation 15 can change the flux of hydrogen sulfide removal from Displays the gas by nano absorber, taking into account the porosity of the substrate.

$$dN_A / dz = R_A(1-\varepsilon) \quad (15)$$

In this formula 14, the N_A is equal to the amount of sulfur transfer from gas stream, Z is equal to the bed elevation path, R_A is equal to the rate of sulfur removal reaction, V is equal to the total volume of the bed, and ε represents the porosity of the bed. The length of the bed with a dz height is divided into several elements. Figure 2 shows the desired length of the element. The boundary conditions in relation 14 are considered in equation 16. C_A is equal to the concentration of hydrogen sulfide in the feed stream.

$$C_A(z=0) = C_{A0} \quad (16)$$

The primary concentration of hydrogen sulfide is the hydrogen sulfide in the feed stream. Also, in equation 16, z = 0 is the length of zero bed, that is, when the fluid is located at the beginning of the bed.

$$N_A = Q\Delta C / SZ \quad (17)$$

The mass transfer rate can be defined as the function of the mass transfer coefficient and the concentration difference as the driving force. As can be seen, the relation 16 shows this definition. The magnetic field can affect the mass transfer coefficient and the reaction strength between the gas phase and the nanoparticles in the water. The emergence of a magnetic field introduces new relationships as the effective mass flow and mass transfer coefficients. These cases reflect the impact of the magnetic field. Relations 18 and 19 express these definitions for the effective mass transfer mass and effective mass transfer coefficients.

$$N_{Aeff} = (N_{Am} - N_A) / N_A \quad (18)$$

$$k_{ave.eff} = (k_{ave.m} - k_{ave.}) / k_{ave.} \quad (19)$$

As the relations 18 and 19 show, first, in the absence of a magnetic field, a mass transfer coefficient and a mass transfer flux are defined, and after applying the electric current and, consequently, producing a magnetic field, a mass transfer coefficient and a mass transfer flux are defined. Then the difference in values obtained to calculate the mass transfer coefficient effective mass transfer flux is used. Generally, the mass transfer coefficient expresses the ability of gaseous and sulfur molecules to sit on active surfaces of nanoparticles, and the mass transfer flux reflects the transfer flux of the pollutant molecules across the entire bed.

3. Results and Discussion

3.1. Investigation of Effective Parameters

In this section of the paper, examines the amount, bed disintegration, the temperature of the incoming gas, the concentration of hydrogen sulfide, the magnetic field, which affects the mass transfer mass, mass transfer coefficient and reaction rate.

3.2. Effect of Initial Concentration and Gas Flow

The gas phase is not pure, so the gas, liquid and solid resistance must be considered in the mass transfer rate. The absorption of hydrogen sulfide in the nano-fluid takes place physically and chemically. Both mechanisms depend on nano-fluid mass transfer media. In this section, the effect of gas flow rate on mass transfer velocity and mass transfer coefficient has been studied. Increasing the initial amount of hydrogen sulfide reduces gas fusion and accelerates the mass transfer rate. An increase in the amount of gas flow increases the apparent velocity of the gas and the fuzzy gas turbulence. This also increases the solubility of hydrogen sulfide in nano-fluid volume.

The Figure 1 shows the effect of gas flow rate and initial concentration of hydrogen sulfide on the mass transfer rate. An increase in gas flow rate will increase the amount of mass flow. This goes back to the high absorption capacity of the nano-fluid and the turbulent regime of flow. In the amount of 22 liters per minute from the amount of gas flow, increasing the amount of initial hydrogen sulfide (from 0.0 to 0.05 moles per cubic meter), the mass flow rate is initially increased and then decreases the reduction of hydrogen sulfide in the flow. This process is similar in both flow rates of 0.27 liter per minute and 0.33 liter per minute, and peak graph is at 0.05

moles per cubic meter of the concentration of hydrogen sulfide in the incoming gas flow. This indicates a limited amount of carbon nanotube capacity. In this case, the positive effect of turbulence on the decrease of fuzzy gas resistance is observed. In other words, the larger amount of force has a significant effect on the increase in the mass transfer rate and the removal of hydrogen sulfide from the gas stream.

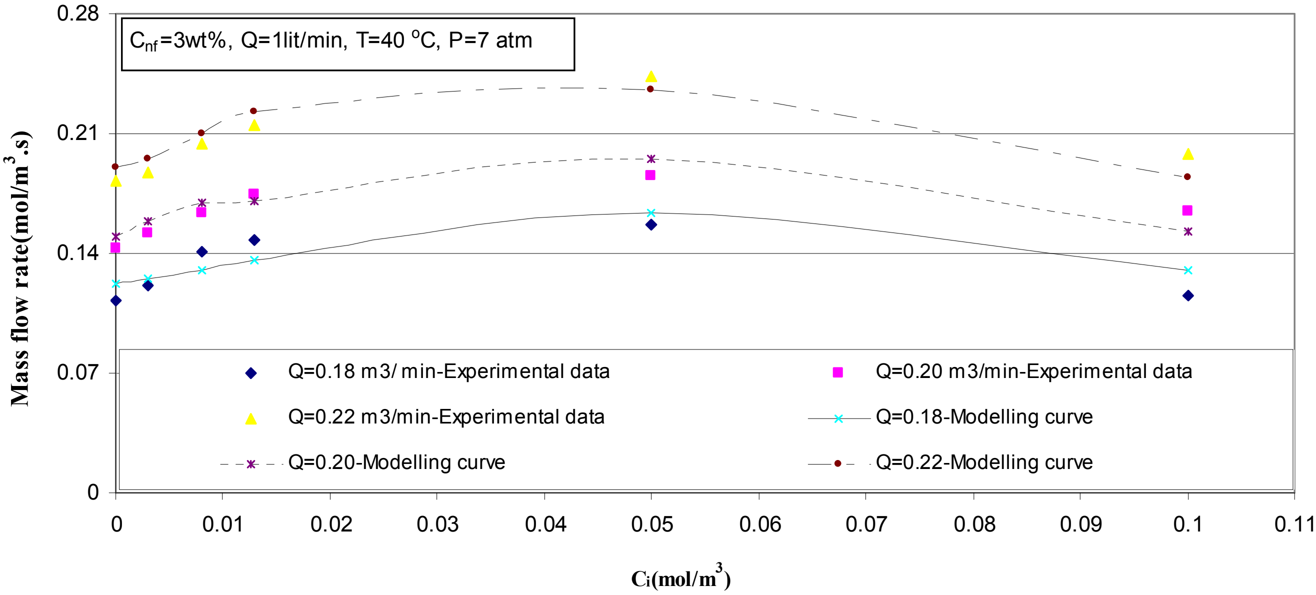

Figure 1. The mass flow rate of the gas in terms of the amount of hydrogen sulfide and gas velocity.

This Figure 2 shows the theoretical and experimental data that are used to identify the model. However, theoretical values are expected in lower limits than the values of laboratory data in some points. This difference may be related to the calculation of the mass transfer coefficient.

The Figure 2 shows the average values of the mass transfer coefficient in the gas phase. In this Figure, an increase in the amount of primary hydrogen sulfide and the amount of gas flow is desired. The absorption process is heat-induced and increases the temperature of the system, so this affects the oscillation and movement of the molecules. Increasing the coefficient may be due to the heat transfer associated with the temperature effect. The turbulent flow also reduces the diffusion distance of hydrogen sulfide in the sour gas phases and increases the mass transfer coefficient.

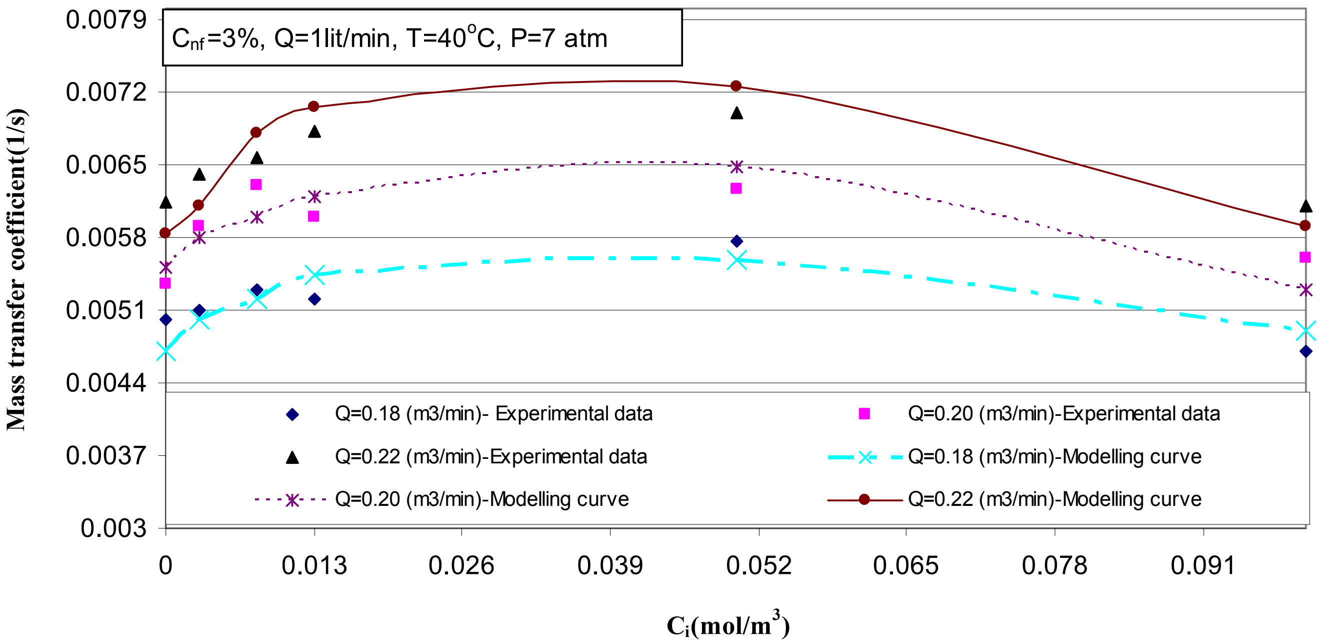

Figure 2. Mass transfer coefficient based on initial concentration of hydrogen sulfide in gas flow.

4. Conclusion

In this paper, a combination of absorption mechanism and magnetism is used to remove hydrogen sulfide from natural sour gas. In this study, the mass transfer mass and mass transfer coefficient are theoretically and practically measured and calculated and measured. The mass transfer flux is introduced as a function of gas temperature, initial concentration of hydrogen sulfide, gas flux rate, magnetic field, nano-fluid flow and weight concentration of carbon nanotubes in pure water. In this article two effective factor for determining the mass flow rate and mass transfer coefficient is determined to indicate the effect of the magnetic field. The magnetic field increases the molecular movement and, as a result, the process temperature is somewhat increased and affects the movement of carbon nanotubes in the nano-fluid layer as well as nano-carbon pipes that are dissolved separately. An effective factor for determining the mass flow rate and mass transfer coefficient is determined to indicate the effect of the magnetic field.

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