MATHEMATICAL MODELING OF THE INSTANTENOUS REACTION OF H₂S –MEA IN A FALLING FILM REACTOR

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ABSTRACT

A mathematical model was formulated using the absorption of carbon dioxide by monoethanolamine amine as an absorbent in a falling film reactor. A program wrote in Fortran language was used to obtain these profiles via using of multi grid method through programming of kinetic and thermodynamic equation and physical properties of the studied system. Through the formulated model film thickness, surface temperature, velocity, concentration and temperature profiles were obtained.

The mathematical analysis validated by a test run in a Baiji refinery through intrusion of liquid flow rate, liquid concentration and gas fraction. In this study we have four factors as independent variables, they are mole fraction of hydrogen sulfide in gaseous mixture (Y) (0.05, 0.75 and 0.1), molar concentration of absorbent (monoethanolamine) (CMEA) (0.05, 0.075 and 1 M), volumetric flow rate of liquor MEA (QMEA) (5, 10, 15, and 20), and its temperature (T) (30, 35, 40, 45, 50 and 55°C).

It is found that the entrance effect of the falling film absorber can be related to the axial distance from the reactor entrance exponentially:-

\[ E = B_0 \exp(-B_1 y) \]

The constants \( B_0 \) and \( B_1 \) were calculated by optimization technique.

The mathematical model describes the effect of the process variables, through the following profiles:

\[ T_s = \frac{h_gT_g + T_{(NGX - 1)}}{h_s} + (\Delta H_s) \left( \frac{k_gk_s}{R_gT_s} \right) \left( p_{h2s} - G \right) \left( \frac{h_g}{h_s} \right) \]
The highest concentration of MEA used in this study (3 M) solution is more efficient in absorption than the lower one (1 M), this is consistent with the recent researchers trend line in using high concentration of MEA solution in the range (2-5) M.

The optimum operating condition for the highest H$_2$S conversion (92.84%) was found to be: C$_{\text{MEA}}$: 3 M, Y: 0.1, Q$_{\text{MEA}}$: 20 L/hr, and T: 55°C.

**KEY WORDS:** Falling film reactor, kinetic, H$_2$S-MEA, modeling.

**INTRODUCTION**

Due to presence of sulfur in the petroleum crude, oil refining inherently involves sour gas treating to remove hydrogen sulfide formed during oil processing.

The principle amines used in amine sweetening plants are MEA, DEA, DGA, DIPA and MDEA. The rate of reaction between the amine molecule and sour gas species are similar for MEA, DEA and DGA. MDEA and DIPA are known as selective amines, because there is a significant difference in the reaction rate between the amine and H$_2$S and CO$_2$. The reaction rate with H$_2$S is fast (instantaneous) with alkanolamine molecules. In comparison, the reaction rate with CO$_2$ is slow due to the intermediate zwitterionic reaction mechanism through a carbonic acid intermediate$^{[1]}$. Falling film gas absorption, in particular, is a very common phenomenon to be encountered in industrial operations specifically in exothermic gas-liquid reactions such as chlorination, sulphonation, nitration, detergent and wetting/dispersing agent industries, polymerization units, fermentation processes and waste disposal systems. Absorption of a gas in a falling liquid film may take place with or without reaction$^{[2]}$. The reactant gas absorbs at the liquid interface due to diffusion perpendicular to the direction of liquid flow. Previous mathematical models for falling film reactors in the field of sulphonation reaction have been...
proposed by Johnson and Crynes\[3\], Davis et al. \[4\], Mann et al. \[5\], Gutierrez et al. \[6\] and Dabir et al. \[7\]. Bhattacharya et al. \[8\] and Nielsen and Villadsen et al. \[9\] studied the gas absorption for chlorination reactions. All these studies predict chemical conversion and interfacial temperatures as the most important variable in product yield and product quality. The aim of the present work is to develop mathematical models for the falling film reactor, which can be used for laminar and turbulent films. The coupled partial differential equations, which describe the mass and heat transfer in the liquid for first and second order reactions are solved by finite difference backward implicit scheme. Many other researchers \[10-16\] enabled the designer to simplify his work by performing their kinetic studies on H\(_2\)S-MEA reactions.

**MATHEMATICAL MODELING**

The mathematical model consist of differential balance equations in the liquid phase with their corresponding boundary conditions. Through these equations, velocity, concentration, and temperature profiles are obtained. The equations are for steady state operation, common in industrial and laboratory reactors.

**1-The Principle Assumptions**

Modeling of the liquid phase was based on the following assumptions:

1) the liquid circulates in a laminar flow, and the gas circulates co-currently in a turbulent flow.

2) The liquid film is symmetric with respect to the reactor axis.

3) The film thickness is small compared to the column radius.

4) Liquid reactant and liquid product are assumed to be nonvolatile at working temperatures.

5) The solubility of the reactant gas in the liquid reactant and in the reaction product is ideal according to Henry's law.

**2-Equations of Mathematical Model**

The column is divided into N number of annular segments figure (1), so we have N number of equations for the liquid reactant and another system with the same number of equations for the dissolved gas.

To formulate a comprehensive model, it must include the effect of hydrodynamic, mass transfer, kinetics, and heat transfer.
2.1 Hydrodynamics

the liquid shear and velocity profiles are obtained using Navier-Stokes equations, which states that for an element volume of moving fluid, the rate of change of momentum equals the net of the forces acting on the element volume

\[ \frac{\partial \mu_t}{\partial x} = \frac{\partial P}{\partial y} + \rho_L g_y \]

mathematically expressed with respect to fig (1) as:

Rate of change viscous force
pressure force gravity force
of momentum on element per + on element

Per unit volume per unit volume
per unit volume per unit volume

\[ \rho_L g_y \frac{\partial \mu_t}{\partial x} = \mu_L \left[ \frac{\partial \mu_t}{\partial x^2} + \frac{\partial^2 \mu_t}{\partial y^2} + \frac{\partial^2 \mu_t}{\partial z^2} \right] - \frac{\partial P}{\partial y} + \rho_L g_y \]

\[ \left(1\right) \]

Which is for steady state one-dimensional flow reduces to:

\[ \rho_L g_y \frac{\partial \mu_t}{\partial y} = \mu_L \frac{\partial^2 \mu_t}{\partial x^2} + \frac{\partial P}{\partial y} = 0 \]

\[ \left(2\right) \]

Or in the form of shear stress:

\[ \rho_L g_y \frac{\partial \mu_t}{\partial y} - \frac{\partial P}{\partial y} = 0 \]

\[ \left(3\right) \]

For a constant axial pressure gradient equation (2) becomes:

\[ \frac{\partial^2 \mu_t}{\partial x^2} = \frac{\Omega}{\mu_L} \]

\[ \left(4\right) \]

Where, \( \Omega = \rho_L g_y \frac{\partial P}{\partial y} = \text{constant} \)

The gas phase exerts an interfacial shear \( \mu_t \) on the liquid film, and the velocity vanishes at the solid boundary, so according to figure (1), we can write the boundary conditions as:

At \( x = \delta \), \( \frac{\partial \mu_t}{\partial x} = \frac{R}{\mu_L} \)

\[ \left(5\right) \]

\( x = 0 \), \( U_y = 0 \)

Hanaratty and Engen, Cohen and Hanaratty, and others have measured interfacial shear in two phase gas-liquid flows, reporting the interfacial friction factor \( \varphi_t \) defined by:

\[ \varphi_t = \frac{R}{\rho_L U_y^2} \]

\[ \left(6\right) \]

Integrating equation (4) twice, and applying boundary conditions, we obtain:

\[ \frac{dU_y}{dx} = -\frac{\Omega}{\mu_L} x + C_1 \]

\[ \left(7\right) \]

\[ U_y = -\frac{\Omega}{2\mu_L} x^2 + C_1 x + C_2 \]

\[ \left(8\right) \]

Substitute equation (5) into (7), to get.

\( C_2 = 0 \)

Substitute equation (6) into (8), to get:
\[ C_1 = \frac{R_i}{\mu_L} + \frac{\Omega \delta}{\mu_L} \]  

\text{Substitute equation (9) into (3-8):}

\[ U_y = -\frac{\Omega x^2}{2\mu_L} + \left[ \frac{R_i}{\mu_L} + \frac{\Omega \delta}{\mu_L} \right] x \]

\[ U_y = \frac{a}{\delta} x - \frac{b}{\delta^2} x^2 \]  

Where:

\[ a = \frac{R_i \delta + \Omega \delta^2}{\mu_L} \] 

\[ b = \frac{\Omega \delta^2}{2\mu_L} \]

Equation (10) describes the velocity profile in the liquid film.

To develop the equation which describes the shear profile through the liquid film; from equations (7) and (9):

\[ \frac{dU_y}{dx} = -\frac{\Omega x}{\mu_L} + \frac{R_i}{\mu_L} + \frac{\Omega \delta}{\mu_L} \]

\[ \mu_L \frac{\partial U_y}{\partial x} = \Omega (\delta - x) + R_i \]  

\[ R = \Omega (\delta - x) + R_i \]  

At the wall, equation (14) becomes,

\[ R_w = \Omega \delta + R_i \]  

From equation (6)

\[ R_i = \phi_i \rho_G U_G^2 \]  

The film thickness is obtained from the volumetric flow rate per unit length of wetted perimeter, (\( Q_L \)) which is related to the velocity distribution by:

\[ Q_L = \int_{0}^{\delta} U_y(x) dx \]

\[ Q_L = \delta \int_{0}^{\delta} \frac{a}{\delta} x - \frac{b}{\delta^2} x^2 dx \]

\[ Q_L = \delta \left[ \frac{a}{2} - \frac{b}{3} \right] \]  

\[ Q_L = \delta \left[ \frac{R_i \delta + \Omega \delta^2}{2\mu_L} + \frac{\Omega \delta^3}{3\mu_L} \right] \]

Equation (19) is cubic equation in (\( \delta \)) which is readily solved by means of \( Q_L \), \( R_i \), \( \Omega \) and \( \mu_L \).

To evaluate the interfacial friction factor (\( \phi_i \)), due to turbulent gas, Blasius equation \(^{[20]}\) is used;

\[ \phi_i = E(0.04) \cdot \text{Re}_G^{0.25} \]  

\( E \) is a correction factor introduced by our model for account of the gas entrance effect, since the gas flow in our experimental work is not fully developed turbulent flow. we assumed further that \( E \) decreases exponentially with the axial distance from the reactor entrance:

\[ E = B_0 \exp(-B_1 y) \]  

\(^{[20]}\)
2.2 Mass Transfer

There is zone of reaction between gaseous solute H$_2$S and liquid reactant MEA, which moves a way from the gas – liquid interface taking up some position towards the bulk of the liquid. The final position of this reaction zone will be such that the rate of diffusion of H$_2$S from the gas – liquid interface equal the rate of diffusion of MEA from the main body of the liquid.

Figure (2) represents the paths of solute (i.e., H$_2$S), liquid reactant (i.e., MEA), and liquid product in the liquid form, so H$_2$S diffuses through the gas film as a result of driving force (P$_G$-P$_i$) and diffuses to the reaction zone as a result of driving force (C$_i$) in the liquid phase. The MEA diffuse from the main body of liquid to the reaction zone under a driving force q, and non volatile product diffuses back to the main bulk of liquid under a driving force (m-n).

2.2.1 Concentration Profile

For H$_2$S (i.e., A component) and MEA (i.e., B component),

- $U_y \frac{\partial C_A}{\partial y} + D_1 \frac{\partial^2 C_A}{\partial x^2} + r_A = 0$ ........(22)

Similarly for liquid reactant (B), the differential balance equation is:

- $U_y \frac{\partial C_B}{\partial y} + D_2 \frac{\partial^2 C_B}{\partial x^2} + r_B = 0$ ........(23)

2.2.2 Boundary Conditions

The boundary conditions required to integrate equation (25) and (26) are:

(a) On y=0, C$_B$= C$_B^0$, C$_A$= 0 ........ (27)
(b) On x=0, $\frac{\partial C_B}{\partial x} = 0$ , $\frac{\partial C_A}{\partial x} = 0$ ...(28)
(c) On x=δ, $\frac{\partial C_B}{\partial x} = 0$ ,

$N_A = K_G (C_A^G - C_A^{IG})$ ...........(29)

Where $N_A = -D_A \frac{\partial C_A}{\partial x}$

The condition (b) indicates that the components mathematically and in fact, can not pass through the wall.

2.2.3 Equilibrium Conditions

(a) Rate of absorption

In the steady state process of absorption, the rate of transfer of material through the gas film will be the same as
that through the liquid film, and the
general equation of mass transfer\([21]\) may
be written as:

\[
N_{H_2S} = \frac{K_{OG}}{R_T S} \left[ p^g_{H_2S} - p_{CO_2}^* \right] \quad \text{.........(30)}
\]

Where:
- \(N_{H_2S}\): molar flux of gaseous reactant
  (\(H_2S\)), kmol/m\(^2\).s
- \(K_{OG}\): overall gas phase mass transfer
  coefficient, m/s
- \(R_T\): gas-liquid interface temperature, K
- \(p^G_{H_2S}\): partial pressure of \(H_2S\) in gas
  phase, N/m\(^2\).
- \(p^*_{H_2S}\): partial pressure of \(H_2S\) in gas phase
  which is in equilibrium with bulk liquid
  phase, N/m\(^2\).

(b) Henry's Constant

Dankwerts \([21]\) mentioned that in
many cases, so long as the concentration
of dissolved gas is small and the
temperature and pressure are far removed
from the critical temperature and pressure
of the gas, Henry's law is obeyed and the
concentration \([H_2S]\) of dissolved gas in
equilibrium with a partial pressure \(P_i\) of
the gas is given by

\[
p^*_{H_2S} = H_e [H_2S] \quad \text{.........(31)}
\]

Where \(H_e\) is the Henry's law constant,
\((\text{N/m}^2), \frac{\text{m}^3}{\text{kmol}})\)

If the gas reacts in solution,
Henry's law does not apply to the total
concentration of unreacted gas.

For the \(H_2S\)-MEA system, at the
temperature range of \((0-100)\ \degree\text{C}\) and \((0.5-
3\ \text{M})\) MEA, Bendall\([22]\) reported a relation
given by:

\[
H_e = 2.3486 e^{-0.0793T_S} \quad \text{.........(32)}
\]

Where \(T_S\) is the gas–liquid interface
temperature K.

c) Conversion of gaseous \(H_2S\)

When \(H_2S\) is absorbed in MEA
solution it reacts according to the
following overall reaction:

\[
H_2S + RNH_2 \leftrightarrow RNH_2H^+ + HS^- \quad \text{.........(33)}
\]

The equilibrium condition is given by:

\[
K = \frac{[RNH_2H^+][HS^-]}{[H_2S][RNH_2]} \quad \text{.........(34)}
\]

\[
p^* = \frac{H_e m Z^2}{K} \quad \text{.........(35)}
\]

Where:
- \(m\): total \(H_2S\) concentration, kmol/m\(^3\)

Astarita \([23]\) proposed a simplification by
replacing \(H_e\) with constant
\[ P^* = 2.4571 \times 10^6 m^{0.25} \frac{Z^2}{1-Z} \exp\left(\frac{-7545}{T_s}\right) \]

Substitute equation (36) into (30);

\[ N_{H,S} = \frac{K_{OG} \left[ \rho_{H,S} - 24571 \times 10^{10} m^{0.25} \frac{Z^2}{1-Z} \exp\left(\frac{-7545}{T_s}\right) \right]}{K_{TS}} \]

......(37)

Conversion = \frac{N_{H,S} \times A_S}{M_{H,S}} .......... (38)

Where:

As: total area of mass transfer, m²

\( M_{H,S} \): Initial molar rate of H₂S, kmol/s.

2.2.4 Mass Transfer Coefficients

a) Gas-Side Mass Transfer Coefficient

\[ K_G = 1 \sqrt{\phi U_G (Sc_G)^{-0.0704}} .......... (39) \]

b) Liquid side mass transfer coefficient

To estimate the liquid side mass transfer coefficient, the correlation of Wilkes\[24]\ is used. They investigated the characteristics of H₂S-H₂O system in a wetted wall column and suggested the following equation:

\[ K_L = 0.523 \left( \frac{3 \mu_L D_L}{\rho_L} \right)^{1/2} \frac{L}{g \mu_L^{1/3}} \]

......(40)

Where:

\( D_L \): diffusion coefficient of solute in liquid, m²/s

\( g \): gravitational constant=9.8 m/sec².

\( L \): length of wetted wall, m.

\( \mu_L \): viscosity of liquid, N.s/m².

\( \rho_L \): density of liquid, kg/m²

\( K_L \): liquid-side mass transfer coefficient, m/s

c) Overall mass transfer coefficient

The overall mass transfer coefficient for the absorbed component CO₂ consist of the gas, and liquid side mass transfer coefficients and is expressed as:

\[ \frac{1}{K_{OG}} = \frac{1}{K_G} + \frac{H_1}{K_L} \]

......(41)

\[ H_1 = \frac{H_r}{R_G T_s} \]

......(42)

Substitute equation (41) into equation (37):

\[ N_{H,S} = \frac{K_G K_L}{R_G T_s (K_G + H_1 K_L)} \left[ \frac{\rho_{H,S} - 24571 \times 10^{10} m^{0.25} \frac{Z^2}{1-Z} \exp\left(\frac{-7545}{T_s}\right)}{1} \right] \]

......(43)

2.3 Heat Transfer

\[ U \frac{\partial}{\partial y} (\rho_L C_p T) = -\frac{\partial}{\partial x} \left( -k_T \frac{\partial T}{\partial x} \right) - \Delta h_{H,S} \]

......(44)

Equation (44) is used to formulate the temperature profile through the column. With the same boundary conditions of item (2.4.1) and gas side mass transfer coefficient of item (2.4.2). Applying Newton- Raphson method on the resultant equation (44) through the main program (NAG Library Software) to
estimate the interfacial H$_2$S–MEA temperature.

3. Solution of the mathematical model

Equations (25), (26) and (44) are two dimensional second order non-linear partial differential equation include:

\[
C_A = f(x, y) \\
C_B = F(x, y) \\
T = S(x, y)
\]

Through the liquid film, where \( f \), \( F \) and \( S \) are functions of two independent variables (i.e., \( x \) and \( y \)). The above equations can not be solved analytically. So this is done numerically. Concentration and velocity profiles will be obtained by means of the same techniques in sections (2.1) and (2.2).

RESULTS AND DISCUSSION

Results of the Present Model

The present model is formulated to predict velocity, concentration, and temperature profiles through the liquid falling-film radially and axially along the reactor. The axial conversion of the solute in the gas phase and the axial interfacial temperature can be also predicted.

Figures (3 to 7) show the output results of the present model, taking a test run of a refinery as an example.

1-Interfacial Temperature Profile

Figure (3) shows the model prediction for the interfacial temperature along the reactor. Analyzing the behavior of the curve indicates an average increase of interfacial temperature (= 8°K) through the first meter of the reactor while through the rest of the reactor the cooling effect of the gas stream begins to diminish the interfacial temperature lower than the initial input temperature of liquid.

2-Concentration Distribution

The present model has the capability to predict concentration profile of the reactants through the liquid film, axially and radially. These are shown in figures (4-6).

Figure (4) shows a linear surface distribution of free hydrogen sulfide concentration in the liquid film. Studying the concentration profiles of figures (4) indicates that the reaction between hydrogen sulfide and monoethanolamine is instantaneous and this is consistent with Davis [4].
3-Temperature Distribution

Figure (5) represents the linear surface distribution of liquid temperature along the reactor. From the mentioned figures we can observe that:

1- The liquid temperature distribution presents a typical bulge shape. This is due to the fact that the exothermic reaction produces heat and the heat is absorbed by the liquid and gas streams. This means that the liquid absorbs most of the heat in the top of the reactor.

2- At constant H₂S content in gas stream, the liquid flow in the column is relatively small, thus the liquid heat capacity is small. As a consequence the liquid temperature gradient at the top of the absorber is very steep. Even though the reaction occurs throughout the column, the temperature starts to decrease in the middle of the column, because the liquid is cooled by the flue gas flowing up the column till a constant value of temperature.

3- The average increase of liquid temperature along the first meter of the reactor length is within (6 °K).

4-Velocity Distribution

Figure (6) represents the linear surface distribution of liquid velocity along the reactor. It can be seen from equation (3) that the maximum liquid velocity occurred at the gas-liquid interface and the minimum value (i.e., \(U_y=0\)) occurred at tube wall, equation (3) is used by the present model to predict the velocity profile in the liquid along the reactor. The parameters influences the velocity profile are gas flow rate, liquid flow rate, liquid viscosity, and tube wall roughness. Liquid velocity is proportional to gas and liquid flow rate while it is inversely proportional to liquid viscosity and tube wall roughness.

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<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Unit (SI System)</th>
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<tbody>
<tr>
<td>C_A</td>
<td>Molar concentration of H_2S in liquid</td>
<td>kmol/m^3</td>
</tr>
<tr>
<td>C_{A_G}</td>
<td>Molar concentration of H_2S in gas</td>
<td>kmol/m^3</td>
</tr>
<tr>
<td>C_{A_{IG}}</td>
<td>Molar concentration of H_2S at gas-liquid interface</td>
<td>kmol/m^3</td>
</tr>
<tr>
<td>C_B</td>
<td>Molar concentration of unreacted H_2S in liquid</td>
<td>kmol/m^3</td>
</tr>
<tr>
<td>C_{B_G}</td>
<td>Initial molar concentration of MEA in liquid</td>
<td>kmol/m^3</td>
</tr>
<tr>
<td>[H_2S]</td>
<td>Molar concentration of MEA in liquid</td>
<td>kmol/m^3</td>
</tr>
<tr>
<td>C_{PG}</td>
<td>Specific heat of gas</td>
<td>J/kg.K</td>
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<tr>
<td>C_{PL}</td>
<td>Specific heat of solution</td>
<td>J/kg.K</td>
</tr>
<tr>
<td>D_A</td>
<td>Molecular diffusivity of H_2S in liquid</td>
<td>m^2/s</td>
</tr>
<tr>
<td>D_B</td>
<td>Molecular diffusivity of MEA in liquid</td>
<td>m^2/s</td>
</tr>
<tr>
<td>D_E</td>
<td>Eddy diffusivity</td>
<td>m^2/s</td>
</tr>
<tr>
<td>g_C</td>
<td>Conversion factor</td>
<td>kg.m/N.s^2</td>
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<tr>
<td>g_y</td>
<td>Gravitational acceleration</td>
<td>m/s^2</td>
</tr>
<tr>
<td>h_G</td>
<td>Gas-side heat transfer coefficient</td>
<td>W/m^2.K</td>
</tr>
<tr>
<td>h_x</td>
<td>Grid spacing in x-direction</td>
<td>m</td>
</tr>
<tr>
<td>H</td>
<td>Henry's law constant</td>
<td>N/m^2.m^3/kmol</td>
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<tr>
<td>ΔH_L</td>
<td>Heat of absorption and reaction of H_2S with MEA solution</td>
<td>kJ/kmol</td>
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<tr>
<td>ΔH_R</td>
<td>Heat of reaction of H_2S with MEA</td>
<td>kJ/kmol</td>
</tr>
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Figure (1) Falling film reactor divided into $N$ annular segments each of length $\Delta y$ and thickness $\delta$.

Figure (2) Physical absorption representation with film theory.

Figure (3) Interfacial temperature profile along the reactor length as predicted by present model for operating condition refinery test run.
Figure (4) Surface distribution of free H₂S concentration in the liquid film for operating condition of Baiji Refiner as predicted by present model

Figure (5) Surface distribution of Temperature through the liquid along the reactor length for operating conditions of Baiji Refinery

Figure (6) Surface distribution of liquid velocity for operating condition of Baiji Refinery
إعداد موديل رياضي للتفاعل اللحظي لغاز ثانوي كيبريتيد الهيدروجين في مفاعل الطبقة المتتالية

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الخلاصة
إن الهيدر مول المقدم هو دراسة تأثير عدد عوامل التي تلعب دورًا معرفًا في امتصاز غاز ثاني كيبريتيد الهيدروجين و هي معدل جزيئات السائل، تركيز المادة المازة، درجة حرارة السائل و الكسر المولي لغاز ثاني كيبريتيد الهيدروجين في المريخ الغازي.

تم تكوين موديل رياضي و تجريبي لنظام امتصاز ثاني كيبريتيد الهيدروجين باستخدام احادي ايثانول الأمين كمادة مازة في مفاعل الطبقة المتتالية.

و هذه أهم المعادلات التي تم التوصل إليها:

\[ T_s = \frac{h_lT_0 + T_{(NGX-1)} - \frac{k_l}{h_x} + (-\Delta H_s) \left( \frac{k_gk_l}{R_gT_s^3} \frac{\rho_G}{H_s + G} \right)}{h_x + \frac{k_l}{h_x}} \]

\[ U_y = -\frac{\Omega x^2}{2\mu_l} + \left( \frac{R_l}{\mu_l} + \frac{\Omega \delta}{\mu_l} \right) x \]

تم تصميم التجربة على نظام العوامل المتتالية و تم دراسة العوامل المؤثرة على تحول غاز ثاني أوكسيد الكربون ضمن المقدرات التالية: الكسر المولي لغاز ثاني كيبريتيد الهيدروجين (0.05، 0.1، و 0.2) و تركيز السائل الماز (0.2، 0.3، 0.4 و 0.5) و معدل جزيئات الحجمي (5، 10، 15، 20) للتراساها و درجة حرارته (35، 40، 45، 50 و 55) م.

تم إعداد برنامج بلغة فورTRAN للحصول الدوال الخاصة بالسرعة و درجة الحرارة و التركيز باستخدام تقنيات الشبكات المتتالية من خلال برمجة المعادلات الحركية والترموديناميكية للنظام و بالاستعانة أيضاً بالخواص الفيزيائية لمكونات النظام.

و تم تحليل على دوال التركيز و درجة الحرارة و السرعة من خلال ذلك البرنامج و كذلك عدة دول.

بعدية أخرى ذات أهمية.

و تم إدخال مجموعة من البيانات الخاصة بظروف التشغيل لذلك البرنامج من خلال التشغيل السيوكي لمصفى الشمال مسحبي (بالنسبة لنظام ثاني كيبريتيد الهيدروجين). و إن مدى انطلاق الموديل الرياضي له علاقة و ثقة ب مدى دقة النتائج.
وقد تبين أن تأثير المدخل لمفاعلاً الطبقة المتغيرة يمكن أن يرتبط بعلاقة أسيوية مع المسافة المحورية تبعاً للمعادلة:

\[ E = B_0 \exp(-B_1 \cdot y) \]

وقد تم استخراج قيم الثوابت ب0 و B1 من النتائج التجريبية و قد تبين أن التفاعل في هذا النظام هو تفاعل وري و التفاعل يحدث عند السطح البيئي.

إن نسبة تحول ثاني كبريتيك الهيدروجين في الطور الغاز تتناسب أسياً مع طول المفاعل.

إن الموديل الرياضي وصف تأثير متغيرات العملية، و هي معدل جريان السائل، درجة حرارته، تركيزه و الكسر المولى ثاني أوكسيد الكربون على معدل الامتصاز.

إن هذا الوصف دل على أن العملية تكون أكثر كفاءة عندما يتم تبريد المفاعل. كما أن التركيز الأعلى للنوع (3 مولاري) يزيد من معدل الامتصاز وهذا يتوافق مع توجه الباحثين حاليًا نحو استخدام التراكمات العالية من الأمين في عمليات امتصاز وثاني كبريتيك الهيدروجين (2-5) مولاري.

الكلمات الدالة

مفاعلاً الطبقة المتغيرة، حركية، نظام غاز ثاني كبريتيك الهيدروجين، احادي اثاثول الأمين، نمذجة