

DEDICATION

This thesis is dedicated to my dear parents, brothers, and to my wife Enas for her endurance, support, and encouragements.

To my supervisors Prof. Babiker Karama Abdalla and Prof. Gurashi Abdalla Gasmelseed Abdalla .

Waleed Nour Eldien Salih

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Waleed Nour Eldien Salih

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ABSTRACT

Many commercial processes are available for the removal of H₂S from gaseous streams. The presence of H₂S in refinery flue gas caused dangerous effect on the environment. Hence, H₂S must be removed from the refinery flue gas, and the relievable mechanism of mass transfer with chemical reactions in a sieve tray column have to be studied. In this study, the chemical absorption of hydrogen sulfide into aqueous ferric sulfate solution Fe₂(SO₄)₃ has been studied. Designed calculations for a sieve tray column have been done and the effective operation parameters on this process have been investigated.

Mass transfer was carried out theoretically by developing a mathematical model of mass transfer phenomena with chemical reaction of H₂S into Fe₂(SO₄)₃ solution in a sieve tray column. The mass transfer process was described by film model, that yielding a second order differential equation solved numerically by orthogonal collocation to estimate enhancement factor. The mass balance model in plate column consists of differential mass balance of H₂S in gas phase and Fe₂(SO₄)₃ in liquid phase giving system of non-linear first order differential equations that were solved numerically by Fourth order Runge-Kutta method under MATLAB Software.

This study assumed steady state and isothermal conditions. In the system studied the refinery flue gas flow rate was, 2.401Ton/h, liquid flow rate was 10000 cm³/s, pressure P is 1atm, temperature 30°C and the concentration of Fe₂(SO₄)₃ in inlet absorbent was 0.002 mol/cm³.

It was found that the percentage of absorbed H₂S can be enhanced by increasing the temperature, liquid flow rate, and Fe₂(SO₄)₃ concentration, decreasing the flow rate of gas.

المستخلص :

هنالك عدة عمليات لازالة كبريتيد الهيدروجين من تيارات الغاز. وجود كبريتيد الهيدروجين في الغازات العادمة له اثر خطير على البيئة، لذلك يجب تنقية الغازات العادمة من كبريتيد الهيدروجين ، وكان لابد من دراسة ظاهرة انتقال المادة المصحوب بتفاعل كيميائي الذي يحدث في برج امتصاص مستخدمين صواني المناخل. في هذه الدراسة تمت دراسة الامتصاص الكيميائي لكبريتيد الهيدروجين في المحلول المائي لكبريتات الحديد $Fe_2(SO_4)_3$ حيث تم تصميم برج الامتصاص وتم التحقق من محددات التشغيل الفعالة لهذه العملية.

تمت دراسة انتقال المادة نظريا" عبر معالجة النموذج الرياضي لظاهرة انتقال المادة مع تفاعل كيميائي لكبريتيد الهيدروجين مع محلول كبريتات الحديد في برج صواني المناخل. عملية انتقال المادة تم وصفها باستخدام نظرية الغشائين ، حيث تم اشتقاق معادلة تفاضلية من الدرجة الثانية التي تم حلها عدديا" بـ Orthogonal Collocation لحساب معامل التحسين. تمت دراسة نموذج موازنة انتقال المادة في برج الصواني لكبريتيد الهيدروجين في الطور الغازي و كبريتات الحديد في طور السائل لتعطي معادلة غير خطية من الدرجة الاولى والتي تم حلها عدديا بواسطة طريقة Runge-Kutta من الدرجة الرابعة وذلك باستخدام تطبيق برنامج الماتلاب.

افتترض في هذه الدراسة ان العملية تتم عند ظروف مستقرة وثبات الحرارة. النظام الذي تم دراسته معدل تدفق للغازات العادمة 2.401Ton/h ، معدل تدفق المذيب السائل $10000cm^3/s$ ، الضغط 1atm ، درجة الحرارة $30^{\circ}C$ ، وتركيز المذيب لكبريتات الحديد $0.002 mol/cm^3$. اثبتت الدراسة انه يمكن زيادة نسبة امتصاص H_2S بزيادة درجة الحرارة ، معدل تدفق المذيب ، و تركيز المذيب مع تقليل معدل تدفق الغاز.

NOMENCLATURE

a	Interfacial surface for mass transfer per unit volume	cm^2/cm^3
A,B	Parameter , dimensionless; see Eq. 3.33	
C	Concentration of substance in solution.	mol/cm^3
C_A	Concentration of gas A	mol/cm^3
C_{A0}	Concentration of A in bulk of liquid	mol/cm^3
C_{Ai}	Concentration of A at interface	mol/cm^3
C_B	Concentration of reactant B	mol/cm^3
C_{BL}	Concentration of B in bulk of liquid	mol/cm^3
C_{Bi}	Concentration of liquid B in inlet stream	mol/cm^3
C_F	Flooding constant for trays, Eq.3.2	
C_o	Orifice coefficient	
D	Tower Diameter, Eq.3.11	cm
D	Diffusivity	cm^2/s
D_A	Diffusivity of dissolved gas A	cm^2/s
D_B	Diffusivity of reactant B	cm^2/s
D_G	Diffusivity of soluble gas in the gas phas	cm^2/s
d_o	Hole diameter	cm
E	Enhancement factor	
E_i	Enhancement factor when reaction is Instantaneous	
F	The Molar diffusion flux	
f	Friction factor	
F_{LV}	Flow factor	
G'	Gas mass flow rate	kg/s
G	Superficial gas mass velocity	$\text{g}/\text{cm}^2.\text{s}$

G_m	Superficial molar gas mass velocity	mol/ cm ² s
G_v	Molar gas flow rate	mol/s
g	Gravitational acceleration	cm/s ²
H_e	Henry's law constant	atm.cm ³ /mol
h_w	Weir height	cm
h_1	Weir crest	cm
k_2	Second order reaction rate constant	cm ³ /mol.s
k_G	Gas phase mass transfer coefficient	mol/cm ² atm.s
k_L	Liquid-film mass transfer coefficient	cm/s
L	Liquid flow rate	cm ³ /s
L'	Liquid mass flow rate	kg/s
m	Order of reaction with respect to A; see Eq 2.43	
M_w	Molecular weight of liquid	g/mol
M	Diffusion reaction parameter	
\sqrt{M}	Hatta Number	
n	Order of reaction with respect to reactant B; see Eq 2.43	
N_A	Molar flux of A	mol/cm ² .s
p_A	Partial pressure of soluble gas in bulk of gas	atm
p_{Ai}	Partial pressure of soluble gas at interface	atm
P	Total Pressure	atm
Q'	Quantity of gas absorbed by unit area in time of contact t	mole/cm ²
Q	Volumetric flow rate of gas	cm ³ /s
q	Volumetric flow rate of liquid	cm ³ /2
r_A	Rate of reaction of A per unit volume.	mol/cm ³ s
R	Rate of absorption per unit area of surface	mol/cm ² s

R'	Average rate of absorption over contact time	mol/cm ² s
Re	Reynolds number	
s	Fractional rate of surface-renewal	s ⁻¹
S	Total area of interface	cm ²
t	Time	s
t	tray spacing	cm
T	Temperature	⁰ C
v	Superficial velocity based on tray tower cross section	cm/s
v_F	Flooding velocity based on A_n	cm/s
W	Weir length	cm
x	Distance beneath liquid surface	cm
X	Parameter , dimensionless; see Eq. 3.33	
x_A	Mole fraction, liquid phase	
y_A	Mole fraction, gas phase	
z	Number of moles of reactant reacting with each mole of	

Greek symbols

α	Empirical constant, Eq.3.3	
β	Empirical constant: for flooding velocity, Eq.3.3	
Γ	Gamma function	
δ	Thickness of diffusion film	cm
δ'	Distance from interface to reaction site	cm
ε	Proportionality constant	
θ	time of exposure of liquid to gas	s

λ	Parameter see Eq. 2.18	
μ	Viscosity of liquid	g/cm.s
μ_g	Viscosity of gas phase	g/cm.s
π	3.14	
ρ_L	Density of liquid	g/cm ³
ρ_G	Density of liquid	g/cm ³
σ	liquid surface tension	dyn/cm

Subscripts

A	Hydrogen sulfid
B	Ferric sulfate
G	Gas phase
L	Liquid phase
∞	at t = infinity

Abbreviations

API	American Petroleum Institute
COS	Carbonyl sulfide
DCU	Delayed Coking Unit
EPA	Environmental Protection Agency
EDTA	Ethylene diamine tetraacetic acid
FCC	Fluid catalytic cracking
KRC	Khartoum Refinery Company
LPG	Liquefied Petroleum Gas
LEL	Lower Explosive Limit
NGL	Natural Gas Liquids
RFCC	Residual Fluid Catalytic Cracking

ppm	Part per million
RSH	Mercaptan
SWS	Sour Water Stripping
TEG	Triethylene Glycol
UEL	Upper Explosive Limit
USEPA	United States Environmental Protection Agency

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