MODELLING AND SIMULATION OF ADSORPTION PROCESS FOR REMOVAL OF CO_2 FROM NATURAL GAS IN AN OFFSHORE PLATFORM

KAUTHAR YUSSUF MAALIM

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School of Chemical and Energy Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

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To my beloved husband

for understanding the days I was away and to my beloved mother for devoting her

time to make sure I complete my studies

Thank You!

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ABSTRACT

The presence of CO_2 in natural gas causes pipeline corrosion and increases operating costs during transfer from the offshore production platforms to the storage terminal. Due to space limitation and harsh operating environment, a robust and compact process such as pressure swing adsorption is preferable. To facilitate the study of process dynamics, simulation studies based on a derived mathematical model on a MATLAB software is presented. The effect of design parameters, focusing on the column height is considered, and it is found that for a typical laboratory scaled apparatus having diameter of 0.5 m. The maximum height required to adsorb 99 % CO_2 is 3 m when the feed flow rate is fixed at 2.5 m^3/s. The size of adsorbent particles is also impacting separation efficiency, and the optimum particle radius is found to be $1.25x10^{-3}$ m and the bed porosity was 0.2. Sensitivity analyses on the main operating parameters are also investigated. It is found that the initial CO_2 feed composition has positive relationship to the adsorption efficiency. The 0.4 mole fraction was found to have sufficient separation efficiency of 90 %. The model is also tested for representing a typical industrial operation with 120 mmscfd. In this case, for a 4 m diameter column, a column height of 20 m is required. This is achieved with a 4 bed PSA system at a flow rate of 10.05 m^3/s for each, and an optimum separation of 87 % is established. Based on the results obtained in this work it can be concluded that the model is a reasonable representation of the system and can be used to obtain the necessary process insights for further process development.

ABSTRAK

Kehadiran CO_2 dalam gas asli menyebabkan kakisan saluran paip dan meningkatkan kos operasi semasa pemindahan dari platform pengeluaran luar pesisir ke terminal penyimpanan. Oleh kerana batasan ruang dan persekitaran operasi yang teruk, proses yang mantap dan padat seperti penjerapan tekanan swing lebih baik. Untuk memudahkan kajian dinamik proses, kajian simulasi berdasarkan model matematik yang diperolehi pada perisian MATLAB dibentangkan. Kesan parameter reka bentuk, yang memberi tumpuan kepada ketinggian lajur adalah dipertimbangkan, dan didapati bahawa untuk alat ukur makmal tipikal yang mempunyai diameter 0.5m. Ketinggian maksimum yang diperlukan untuk menyerap 99% CO_2 ialah 3 m apabila kadar aliran suapan ditetapkan pada $2.5m^3/s$. Saiz zarah penyerap juga memberi kesan kepada kecekapan pemisahan, dan radius zarah optimum didapati $1.25x10^{-3}$ m dan porositi katil adalah 0.2. Analisis kepekaan terhadap parameter operasi utama juga disiasat. Telah didapati bahawa komposisi makanan CO_2 awal mempunyai hubungan positif dengan kecekapan penjerapan. Pecutan 0.4 mol didapati mempunyai kecekapan pemisahan yang mencukupi sebanyak 90%. Model ini juga diuji untuk mewakili operasi perindustrian biasa dengan 120 MMSCFD. Dalam kes ini, bagi lajur diameter 4 m, ketinggian lajur 20 m diperlukan. Ini dicapai dengan sistem PSA 4 katil pada kadar aliran 10.05 m^3/s untuk setiap satu, dan pemisahan optimum 87% ditubuhkan. Berdasarkan hasil yang diperolehi dalam karya ini, dapat disimpulkan bahwa model adalah representasi yang wajar dari sistem dan dapat digunakan untuk memperoleh wawasan proses yang diperlukan untuk pengembangan proses selanjutnya.

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LIST OF ABBREVIATIONS

CCS	-	Carbon Capture and Storage
CO_2	-	Carbon dioxide
FPSO	-	Floating Production Storage Off-loading
GDP	-	Gross Domestic Product
LPH	-	Litter per hour
MEA	-	Monoethanol Amine
MOFs	-	Metal-organic frameworks
MOPs	-	Microporous organic polymers
MSA	-	Microwave Swing Adsorption
PI	-	Process Intensification
Ppmv	-	parts per million volume
PSA	-	Pressure Swing Adsorption
TSA	-	Temperature Swing Adsorption

LIST OF SYMBOLS

L	-	Column Length
D	-	Column Diameter
ε	-	Voidage
Rp	-	Particle Radius
kt	-	Volumetric Mass Transfer Coefficient
u	-	Gas Velocity
K	-	Freundlich Constants
n	-	Freundlich Constants
T	-	Temperature
R	-	Universal Gas Constant
ρ_s	-	Density of Solid
P	-	Pressure
$\dot{V}$	-	Volumetric Flow Rate
$\dot{V}$	-	Standard Volumetric Flow Rate
$\dot{M}$	-	Mass Flow Rate
C	-	CO_2 Concentration
q	-	Amount of CO_2 Adsorbed
q_e	-	Equilibrium Quantity Adsorbed
C_p	-	Specific heat capacity

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Natural gas is a good candidate replacement fuel for heavy fossil fuel such as fuel oil or diesel, commonly used in power plants (Beronich *et al.*, 2009). It is a gas formed from decomposition of the animals and plants that died over 400 million years. It is used for both lighting and heating. Nearly one quarter of global energy production is from natural gas, with which at the year 2004 had an increasing rate of 3.3 % (Group, 2005). Natural gas is very attractive source of energy because it has low CO_2 emission as compared to other fuels like coal and oil (Beronich *et al.*, 2009). Moreover, NG has been widely studied as an important alternative for the expansion of the world's energy supply (Rios *et al.*, 2011; Walton *et al.*, 2006).

In natural gas, CO_2 is found at an average composition of 0.5 to 10 vol.% (Rios *et al.*, 2013). However, in certain fields, the content can be much higher. The presence of CO_2 in natural gas has several disadvantages such as lowering the heating value. Also, the volume of natural gas to be handled is increased and thus increasing the handling cost (Ahmed and Ahmad, 2011). The presence of water in natural gas causes reactions between water and CO_2 producing acid which is responsible for corrosion of metal pipes (Birkelund, 2013).Thus, most of the gas treatment facilities are designed with the limitation to treat natural gas with reduced CO_2 content by 30 to 40 mole %. Therefore, there is a need to remove the CO_2 at source to reduce transportation load and the risks of pipeline corrosion. This is even more important for the case of natural gas produced in offshore fields, where gases are transported by pipelines to onshore gas terminals.

Typically, CO_2 is removed either using membrane processes, chemical absorption or pressure swing adsorption. However, membrane separation suffers from gas losses due to membrane saturation, the life time and durability of membrane and chemicals used for absorption are poor (Ahmed and Ahmad, 2011). Also, aqueous amine solution has effects of corrosion, high energy consumption for regeneration and requires large volume of absorber (Veawab et al., 1999). In addition, there is high operation cost due the fact that both membrane and chemical solvents separation requires pre- treatment to remove the impurities that may degrade the solvent or membrane. Based on these disadvantages more stable, efficient and cost-effective gas separation methods are to be developed to overcome such challenges.

A preferred alternative, especially from robustness perspectives is adsorption. However, there are several issues needed to be addressed. These include developments of better adsorbent and better process configurations especially in the context of offshore production platforms where space is limited. A compact and efficient process is therefore needed as the system is constrained by the limited space in these offshore production platforms.

1.2 Problem Statement

On-site removal of CO_2 is advantageous as it reduces all the associated costs and problems in transporting the overall costs of transporting natural gas using pipelines from offshore production platforms. This is however, a challenging task because of space limitations (Dalane et al., 2017; Mazzetti et al., 2014). Although there are many options available, most are not practicable due to various issues. Membrane separation suffers from durability issue, while amine absorption liquid amine that requires large space, energy intensive regeneration cycle and waste disposal issue. On the contrary, Pressure Swing Adsorption (PSA), which is a robust physical process offers a clear advantage. However, in order to design a compact system to be applied in harsh processing environment. The process must be well understood. This requires detailed studies on the sensitivity and dynamics of the process variables, which can be facilitated through mathematical modelling and simulation studies of the PSA system. Based on these understandings, detailed equipment design can later be carried out to suit the desired application.

1.3 Research Objectives

The aim of the work is to study the characteristics of PSA process for separating CO_2 from natural gas mixture. This is achieved by satisfying the following research objectives:

i. To develop mathematical model of the CO_2 adsorption process and simulate the model using MATLAB software
ii. To carry out sensitivity analysis of key design and process variables and their influence on the separation of CO_2 from natural gas stream that contains high CO_2

1.4 Scope of Study

This research focused on simulation of CO_2 adsorption. There are many parameters that can be studied to determine the optimum adsorption conditions for CO_2. For the purpose of this research, effects of gas velocity, height of the column and initial CO_2 composition in natural gas was studied. The sizing of the bed was optimized and the optimum operating conditions were examined. The height variation was from 1m to 4m at the small scale which was further optimized for the industrial operation. The initial CO_2 composition (mole fraction) was varied from 0.2 to 0.6 this range was selected because the given CO_2 mole fraction natural gas is around 0.4 in most of the fields. In addition, the feed flow rate was varied from

$1\text{m}^3/\text{s}$ to $5\ \text{m}^3/\text{s}$ which was then optimized to accommodate the actual flow rate at the gas processing plants.

1.5 Significance of Study

The ability to remove CO_2 on-site in an offshore platform with a reduced equipment size offer major benefits to the industry. The outcome of this study provides a useful guide for studying various alternatives for system configurations to be applied in space scarce processing environment such as off-shore production platform and Floating Production Storage Off-loading (FPSO) system.

The compact size of PSA at the offshore gas processing plants is more efficient since less space is needed. Also there will be a needed of less construction materials since the size of columns needed are smaller as compared to the conventional one. Thus reducing both installation and maintenance costs. Moreover the use of new adsorbent will also be significant because smaller column size require less adsorbent and that most of the time new adsorbent are available in abundant form.

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