Faculty of Engineering

MODELLING AND OPTIMIZATION OF CO_2 EMISSION IN PEFB DERIVED BIO-SYNTHETIC NATURAL GAS PRODUCTION VIA PHYSICAL ABSORPTION

Mohamad Afiq Bin Mohd Asrul

Bachelor of Engineering with Honours

(Chemical Engineering)

2020

UNIVERSITI MALAYSIA SARAWAK

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This final year project 2 report which entitled **"Modelling & Optimization of CO_2 Emission in PEFB Derived Bio-Synthetic Natural Gas Production via Physical Absorption"** was prepared by Mohamad Afiq Bin Mohd Asrul (58718) as a partial KNC 4344 Final Year Project 2 course fulfilment for the Degree of Bachelor of Chemical Engineering is hereby read and approved by:

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(Final Year Project's Supervisor)	

MODELLING & OPTIMIZATION OF CO_2 EMISSION IN PEFB DERIVED BIO-SYNTHETIC NATURAL GAS PRODUCTION VIA PHYSICAL ABSORPTION

MOHAMAD AFIQ BIN MOHD ASRUL

A dissertation submitted in partial fulfilment

of the requirement for the degree of

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Dedicated to my beloved family and friends.

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ABSTRACT

The final year project titled modelling and optimisation of carbon dioxide (CO_2) emission in palm empty fruit bunch (PEFB) derived bio-synthetic natural gas production via physical absorption has been reported. The anthropogenic CO_2 emission has responsibility for global warming and climate changes which contributed significantly by the heavy utilisation of conventional fossil fuel power to meet the need of humankind. Biomass is a potential alternative source of energy to replace the dependency of fossil fuel reserves that expected to undergo long term depletion and considering the environmental conservation through CO_2 natural emission life cycle. Biomass conversion to energy even has no exception in releasing CO_2 which could be mitigated by the introduction of biogas purification unit to be incorporated with waste to energy (WtE) technology. The massive increase of agriculture waste accumulation in Malaysia like PEFB can be inverted into a potential feedstock of thermal WtE plant to generate valuable and clean bio-synthetic natural gas for electricity and heat utility. Considering the sluggish development of WtE in Malaysia, the mathematical model on the physical absorption of CO_2 from dried PEFB derived bio synthetic gas production is established and optimised to achieve a green manufacturing tariff including the model capability to serve 95 – 98 % CO_2 removal efficiency and finalised operating design of modelled CO_2 absorber is optimal for the dried PEFB derived bio-synthetic natural gas with CO_2 concentration at 40.051 mole % and below. The performance of the validated model for CO_2 absorption by physical solvent dimethyl ether polyethylene glycol (DEPG) could be optimised by carrying out sensitivity analysis based on the variation of temperature, operating pressure and liquid to gas (L/G) stream flowrate ratio. The modelling finding has shown that the satisfactory CO_2 reduction efficiency of CO_2 physical absorption in the PEFB derived bio synthetic gas production could be met optimally at T = 31.0 ^oC, P = 1.6 kPa and L/G = 1:1.

Keywords: *Carbon dioxide capture, Physical absorption rate-based model, Dimethyl ether polyethylene glycol solvent, Palm empty fruit bunch-derived bio-synthetic natural gas*

ABSTRAK

Projek tahun akhir bertajuk pemodelan dan pengoptimuman pelepasan karbon dioksida (CO_2) dalam pengeluaran gas natural bio-sintetik hasil tandan kosong buah sawit (TKBS) telah dilaporkan melalui penyerapan fizikal. Pelepasan CO_2 antropogenik bertanggungjawab terhadap pemanasan global dan perubahan iklim yang menyumbang secara besar-besaran oleh penggunaan tenaga bahan bakar fosil konvensional yang berat untuk memenuhi keperluan umat manusia. Biomas adalah sumber tenaga alternatif yang berpotensi untuk menggantikan kebergantungan simpanan bahan bakar fosil yang dijangkakan akan mengalami pengurangan dalam jangka masa panjang dan mempertimbang pemuliharaan alam sekitar melalui kitaran hidup pelepasan semula jadi CO_2. Penukaran biojisim kepada tenaga bahkan tidak terkecuali dalam melepaskan CO_2 yang dapat dikurangkan dengan pengenalan unit pemurnian biogas untuk disatukan dengan teknologi sisa kepada tenaga (SkT). Pengumpulan sisa pertanian yang semakin meningkat di Malaysia seperti TKBS dapat diubah menjadi bahan baku tanaman SkT termal yang berpotensi untuk menghasilkan gas natural bio-sintetik yang berharga dan bersih untuk bekalan elektrik dan haba. Memandangkan perkembangan SkT yang sedikit ketinggalan dan lambat di Malaysia, model matematik mengenai penyerapan fizikal CO_2 daripada pengeluaran gas natural bio-sintetik kering TKBS dibuat dan dioptimumkan untuk mencapai tarif pembuatan hijau termasuk kemampuan model untuk menepati 95 – 98 % kecekapan penyingkiran CO_2 dan reka bentuk operasi akhir penyerap CO_2 yang dimodelkan adalah optimum untuk gas bio sintetik TKBS kering dengan kepekatan CO_2 pada 40.051 mol % ke bawah. Prestasi model yang disahkan untuk penyerapan CO_2 oleh pelarut fizikal dimetil eter polietilena glikol (DEPG) dapat dioptimumkan dengan melakukan analisis kepekaan berdasarkan variasi suhu, tekanan operasi dan nisbah kadar aliran cecair kepada gas (L/G). Penemuan pemodelan menunjukkan bahawa kecekapan pengurangan CO_2 yang memuaskan daripada penyerapan fizikal CO_2 dalam pengeluaran gas sintetik bio yang dihasilkan TKBS dapat dipenuhi secara optimum pada suhu T = 31.0 ^oC, P = 1.6 kPa dan L/G = 1:1.

Kata kunci: *Penangkapan karbon dioksida, model berdasarkan kadar penyerapan fizikal, pelarut Dimetil eter polietilena glikol, Gas natural bio-sintetik hasil tandan kosong buah sawit*

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

AAD	: Average absolute deviation
AD	: Absolute deviation
AMP	: 2 – amino – 2 methyl – 1 propanol
CAPEX	: Capital expenditures
CCS	: Carbon and sequestration
CO	: Carbon monoxide
CO_2	: Carbon dioxide
CH_4	: Methane
DEPG	: Dimethyl ethers and polyethylene glycol
DOE	: Department of Environmental
EOS	: Equation of state
GHG	: Greenhouse gas
H_2	: Hydrogen gas
H_2O	: Water
HPWS	: High pressure water scrubbing
IEA	: International Energy Agency
IPCC	: Intergovernmental Panel on Climate Change
K – E	: Kent – Eisenberg
L/G	: Liquid to gas ratio
LTSR	: Low temperature steam reforming
MEA	: Monoethanolamine
N_2	: Nitrogen gas
NaOH	: Sodium hydroxide
NEQ	: Non – equilibrium
NO_2	: Nitro dioxide
NMP	: N – methyl pyrrolidone
ODE	: Ordinary differential equation
OPEX	: Operational expenditures
PC	: Propylene carbonate
PDE	: Partial differential equation
PEFB	: Palm Empty Fruit Bunch

POME	: Palm oil mill effluent
PR	: Peng Robinson
PZ	: Piperazine
S/C	: Steam to carbon ratio
VLE	: Vapour liquid equilibrium
WtE	: Waste to energy

UNITS

atm	: Atmosphere
bar	: Bar
cm^3	: Centimetre cubic
^oC	: Degree Celsius
^oF	: Degree Fahrenheit
ft	: Feet
ft^3	: Feet cubic
h	: Hour
J	: Joule
K	: Kelvin
kPa	: Kilo pascal
kg	: Kilogram
MPa	: Mega pascal
m	: Metre
m^3	: Metre cubic
mm	: Millimetre
mmHg	: Millimetre mercury
mol	: Mole
%	: Percentage
lb	: Pound
s	: Second
vol %	: Volume percent
wt %	: Weight percent

NOMENCLATURE

Θ	: loading rate of absorbent
ΔH_{Abs}	: heat of absorption in J/mol
ΔH_S	: heat of vaporisation in J/mol
A_c	: cross - sectional area of column in m^2
A_e	: interfacial effective area of packing per unit column volume in m^2/m^3
A_t	: total surface area of the packing per unit volume of the column in m^2/m^3
c_i	: molar concentration of component i in mol/m^3
cp_i	: specific heat capacity of component i in J/kg.K
D_i	: diffusivity of component i in m^2/s
d_p	: nominal size of packing in m
E	: enhancement factor
f	: fugacity of gas component in Pa
g	: gravitational due to acceleration = 9.8 m/s^2
G	: total molar gas flow rate in mol/s
h	: heat transfer coefficient in $W/m^2.K$
He_{CO_2}	: Henry's law constant of CO_2 in Pa
K	: overall mass transfer coefficient of component i in $mol/m^2.s.Pa$
k_G	: mass transfer coefficient of component i at gas side in $mol/m^2.s.Pa$
k_L	: mass transfer coefficient of component i at liquid side in m/s
L	: total molar liquid flow rate in mol/s
M_i	: molecular weight of component i in kg/mol
N_i	: mass flux of component i in $mol/m^2.s$
$N_{i,gen}$	: rate of generation of component i in the liquid phase in $mol/m^3.s$
P	: total pressure of the system in Pa
p_i	: partial pressure of component in Pa
$p_{i,e}$	: partial pressure of component at equilibrium in Pa
q	: heat flux in $J/m^2.s$
R	: gas constant in $Pa.m^3/mol.K$
T	: temperature in K
u_G	: gas side velocity in m/s
u_L	: liquid side velocity in m/s

x_G : liquid – phase mole fraction at the bulk

x_i : liquid – phase mole fraction at the interphase

y_G : gas – phase mole fraction at the bulk

y_i : gas – phase mole fraction at the interphase

z : distance of the absorption tower from bottom surface of column in m

γ_i : activity coefficient of component

λ : liquid hold up

μ_i : viscosity of component i in kg/m.s

ρ_i : density of component i in kg/m^3

σ_C : critical surface tension of liquid in kg/hr^2

σ_L : surface tension of liquid in kg/hr^2

SUBSCRIPTS

Amb, 0	: ambient or at standard room condition
e	: equilibrium or interface of vapour or liquid side
G	: gas phase
i	: interfacial phase
j	: component including CO_2, H_2O, liquid solvent
L	: liquid phase
t	: time
tot, ov	: total, overall

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The expansion of energy demand globally in line with the growth of compressed population and associated economic development have exhibited to the anthropogenic emission of highly concentrated carbon dioxide (CO_2) gas in the atmospheric surface of the earth, causing the global warming and climate changes. CO_2 is considered as a harmful gaseous in the excessive volume of gas escaped resulted by the fuel combustion to allow energy conversion for power and heat supply besides to accommodate the rapid industrialisation. The Intergovernmental Panel on Climate Change (IPCC) model as accessed by Barker et al. (2007) have shown that the elevation of global surface temperature from the year 1990 to 2100 is predicted within the range of 1.1 – 6.4 °C. This has led the introduction of waste to energy (WtE) technologies in the energy industry by strengthening the eco-friendly biomass as a feedstock for a sustainable renewable energy production apart from ensuring effective waste management. However, the development of WtE is a quite challenging job in the effort to control the global CO_2 emission. Biomethane is one of WtE product which could replace the strong dependency of fossil fuel gas that is expected to undergo depletion as time ahead beside in endeavour to allow the degradation of global environmental impacts by the conversion of biomass. Palm empty fruit bunch (PEFB) is attractive biomass which highly available in Malaysia due to abundance of palm oil tree plantation area across the state and recognised to be a side income among the local farmer by the legal sale of electricity directly to the national grid. However, the numerous or large scale of PEFB conversion to biogas has subjected to the in turn of CO_2 emission that equivalent environmental impact as conventional fossil fuel combustion, thus it becomes a current drawback of these WtE facilities. The operational and economic circumstances in the biofuel gas plant are responsible for the presence of CO_2 in the biogas stream (Motahari et al., 2015). Green manufacturing of biomethane could be achieved by incorporating the CO_2 capture unit in the biogas thermal WtE technology. As compared to Europe, the advancement of CO_2

purification for upgrading the raw biogas calorific value in Malaysia is slightly sluggish and generally can be considered at the initial phase. Regard to the above statement, the modelling of CO_2 emission control in the thermochemical conversion of PEFB feedstock into bio synthetic gas by physical absorption is established using mathematical model approaches.

1.2 Problem Statements

Malaysia as the third - largest contributor of CO_2 emission in South East Asia with total local CO_2 escaped of 54.8 % is exhibited by the strong dependency of the national power sector based on conventional fossil fuel (Haiges et al., 2017; Abdeshahian et al., 2016). Due to current technology and economic constraints, the renewable energy capacity is reported inadequate to meet the increasing of world energy demand (He et al., 2013). The annual agriculture crop of processed palm oil fruit in respect to the massive plantation of palm oil tree have subjected to the abnormal emission of CO_2 neutral due to biological uncontrolled of anaerobic digestion by the fermenting fruit bunch in the open air with the presence of sunlight.

The latest CO_2 capture technology in Malaysia seems under rating due to lack of government and institutional support which made the acceptance of national climate change policies among the local palm oil mill owner have gained less responsive. The conventional physical absorption in the palm oil solid WtE plant is remained to suffer from the technical penalty to serve a high rate of CO_2 capture in the renewable energy generation as it tied by both capital expenditures (CAPEX) and operational expenditures (OPEX).

Minor established model for CO_2 absorber without reaction compared to with chemical reaction is recognised due to unique assumptions and mathematical equation to reflect the mechanism of the CO_2 in chemical absorption which might infeasible for the physical solvent application. The complexity of the equations in the model to be computed numerically as resulted by the general assumptions of the absorption conditions have caused the model implementation to be a time - consuming and large error of expected results is difficult to be solved. None of the recent findings of modelled CO_2 absorption (Pandya, 1983; deMontigny et al., 2006; Gabrielsen et al., 2006; Shahid et al., 2019) is incorporated with physical solvent as absorbent and the capability of the model to be applied without chemical reaction requirement to the green manufacturing tariff including efficient reduction of GHG as referred to CO_2 and conservation of natural resources based on the reliability of the CO_2 physical