CARBON DIOXIDE MANAGEMENT FOR PRODUCT SUPPLY CHAIN AND TOTAL SITE UTILISATION AND STORAGE

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CARBON DIOXIDE MANAGEMENT FOR PRODUCT SUPPLY CHAIN AND TOTAL SITE UTILISATION AND STORAGE

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Chemical Engineering)

School of Chemical and Energy Engineering
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OCTOBER 2018

I declare that this thesis entitled *"Carbon Dioxide Management for Product Supply Chain and Total Site Utilisation and Storage"* is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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To my beloved husband, Muhammad Faizal

Umairah, Umaiza,Uzayr

Ibu, Bapak, Mak, Abah and family members

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful

All praises to Allah for bestowing the health, strengths and opportunity for me to experience this valuable path in completing this thesis. The knowlegde and experiences gained throughout the process is aprecious treasure that will not be forgotten.

First and foremost, I would like to express my utmost appreciation and highest gratitude to my supervisor, Professor Ir. Dr. Sharifah Rafidah Wan Alwi and my co-supervisors, Professor Dr. Zainuddin Abdul Manan and Professor Dr. Jiří Jaromír Klemeš for their myriad constructive comments and unwavering support to the completion of this research. Their guidance and encouragement are gratefully acknowledged.

In addition, I would like to take this golden opportunity to thank my husband Muhammad Faizal Zainal Abidin, my children, my parents and family members for their unconditional continuous support and encouragements. Also, I wish to express my great appreciation for my fellow post-graduate friends and staffs at Process System Engineering Center (PROSPECT-UTM) or other unmentioned parties who have, directly and indirectly, providing their sincere guidance and support to the completion of this research.

I would also like to recognise the tremendous financial support granted by Universiti Malaysia Pahang (UMP) and Ministry of Education Malaysia through the SLAB-SLAI scheme scholarship. Above all, I thank Allah for the grace, mercy and guidance that enable the successful completion of this journey.

ABSTRACT

The development of insight-based graphical and algebraic techniques in process integration (PI) for carbon dioxide (CO_2) emission targeting, design, and planning based on pinch analysis (PA) has evolved in line with the developments of other PI tools for the conservation of resources including heat, mass, gas, power, and electricity. Complementary PA-based tools can provide graphical and visualisation insights that are vital for better conceptual understanding of problems, particularly at the onset of CO_2 emission systems planning and design, have been developed over the last ten years. Therefore, a comprehensive and systematic CO_2 emission reduction planning and management using PA-based methods are proposed in this research to provide a systematic and vital insights towards CO_2 emission reduction. This research proposes a methodology for CO_2 emission reduction throughout product supply chain and end-of-pipe management of CO_2 via total site integration. A palm cooking oil product is used to demonstrate the proposed methodology development. In the first step, CO_2 emission hotspot which contributes the highest emission phase in the supply chain is identified. Next, the most suitable and economically viable CO_2 reduction strategies are identified and screened by using CO_2 management hierarchy as a guide, and SHARPS as a cost screening technique. At this stage, a total of 1,077 tonnes per year (t/y) CO_2 emissions for a basis of 100 t/y of palm cooking oil production are successfully reduced to 402 t/y which is approximately 63% reduction based on the implementation of CO_2 emission reduction strategies that achieved target payback period (TPP $\leq$ 2 years) and investment cost (INV $\leq$ USD 150,000). In the third step, the remaining CO_2 emission could be further reduced with end-of-pipe emission management considering multiple sites which can act as CO_2 sources or demands. A methodology for total site CO_2 integration is introduced to integrate and fully utilise the CO_2 emissions among industries and/or plants via single and multiple centralised header before being sent to storage to permanently store and zero CO_2 emissions can be achieved via single header. Finally, CO_2 purification and pressure drop are considered during CO_2 transportation in the total site CO_2 integration system's design. An algebraic approach called CO_2 utilisation and storage-problem table algorithm is proposed to obtain total site target for integration of CO_2 utilisation and storage. In conclusion, a new integrated methodology of CO_2 emission reduction for product supply chain and CO_2 end-of-pipe management has been successfully developed. This new methodology is expected to enable planners, policy makers or designers to plan and manage their CO_2 emissions reduction effectively as well as systematically planning for resource conservation.

ABSTRAK

Pembangunan proses bersepadu (PI) berdasarkan teknik grafik dan algebra untuk sasaran pelepasan karbon dioksida (CO_2), reka bentuk dan perancangan berdasarkan analisa jepit (PA) telah berkembang sejajar dengan perkembangan metodologi PI yang melibatkan pemuliharaan sumber termasuk haba, jisim, gas, kuasa dan elektrik. Metodologi pelengkap berasaskan PA yang telah dibangunkan sejak sepuluh tahun lepas menyediakan grafik dan pandangan visual yang mana penting untuk pemahaman konsep permasalahan reka bentuk dan perancangan bagi sistem pelepasan CO_2. Oleh itu, perancangan dan pengurusan pelepasan CO_2 yang komprehensif dan sistematik berasaskan PA dicadangkan dalam kajian ini bagi menyediakan pengamatan penting dan sistematik terhadap pengurangan pelepasan CO_2. Kajian ini memperkenalkan metodologi pengurangan pelepasan CO_2 menerusi produk rantai bekalan serta pengurusan akhir-paip pelepasan CO_2 melalui CO_2 seluruh tapak bersepadu. Pembangunan metodologi dilaksanakan menerusi produk minyak masak kelapa sawit. Pada mulanya, fasa titik panas pelepasan CO_2 iaitu fasa pelepasan CO_2 yang tertinggi dalam rantai bekalan dikenalpasti. Seterusnya, strategi-strategi pengurangan CO_2 yang paling sesuai dan ekonomik dikenalpasti dan disaring berdasarkan hierarki pengurusan CO_2 sebagai panduan dan teknik penyaringan kos SHARPS. Pada peringkat ini, pelepasan CO_2 sebanyak 1,077 tan per tahun (t/t) dari 100 t/t asas produk minyak masak kelapa sawit telah berjaya dikurangkan kepada 402 t/t dengan anggaran pengurangan sebanyak 63% berdasarkan pelaksanaan strategi pengurangan pelepasan CO_2 yang mencapai sasaran tempoh pulangan balik (TPP $\leq$ 2 tahun) dan kos pelaburan (INV $\leq$ USD 150,000). Pada langkah ketiga, baki daripada jumlah pelepasan CO_2 setelah metodologi pengurangan CO_2 dilaksanakan, dapat dikurangkan lagi dengan pengurusan akhir-paip pelepasan CO_2 yang mempertimbangkan tapak-tapak industri sebagai sumber pelepasan CO_2 atau permintaan penggunaan CO_2. Metodologi CO_2 seluruh tapak bersepadu telah diperkenalkan untuk menyepadukan dan menggunakan pelepasan CO_2 dengan sepenuhnya di kalangan industri dan/atau loji-loji melalui sistem terusan tunggal dan pelbagai berpusat sebelum dihantar ke simpanan secara kekal dan sifar pelepasan CO_2 boleh dicapai menerusi sistem terusan tunggal. Akhirnya, proses ketulenan CO_2 dan susutan tekanan sepanjang pengangkutan CO_2 dalam reka bentuk sistem CO_2 seluruh tapak bersepadu telah dipertimbangkan. Pendekatan algebra penggunaan dan simpanan CO_2 masalah jadual algoritma telah diperkenalkan untuk mendapatkan sasaran seluruh tapak bagi penggunaan dan simpanan CO_2 bersepadu. Sebagai kesimpulan, kaedah bersepadu baru pengurangan pelepasan CO_2 untuk rantaian bekalan produk dan pengurusan akhir paip CO_2 telah berjaya dibangunkan. Metodologi baru ini dijangka dapat membolehkan perancang, pembuat dasar atau pereka untuk merancang dan mengurus pengurangan pelepasan CO_2 mereka dengan berkesan serta merancang pemuliharaan sumber dengan sistematik.

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LIST OF ABBREVIATIONS

Set

i	-	Index for supply chain phase
j	-	Index for CO_2 reduction strategy
k	-	Index for CO_2 source
q	-	Index for CO_2 demand

Variable

CO_2^R	-	Value of CO_2 emission reduction
ES_{CO2}	-	CO_2 emission
F_{CO2}		CO_2 flowrate
$FC\text{-}D$	-	Fresh CO_2 flowrate to demand
$FC\text{-}H1$	-	Fresh CO_2 flowrate to header 1
F^D	-	After purified flowrate
F^G	-	Tail gas flowrate
F_{OG}	-	Other gas flowrate
FP_{in}	-	Feed flowrate to purify
F_T	-	Flue gas flowrate
INV^{after}	-	Investment after SHARPS
$INV^{initial}$	-	Investment before SHARPS
INV^{set}	-	Desired investment
$INV^{strategy}$	-	Individual investment for each of the strategy
m	-	Gradient of strategy
$P_{CO2}{}^{H1}$	-	CO_2 purity of the header 1
$P_{CO2}{}^{H2}$	-	CO_2 purity of the header 2
P^D	-	Purified product purity
$Q^{base\ case}$	-	CO_2 emission before reduction
$R^{strategy}$	-	Individual contribution of CO_2 emission reduction for each of the strategy
$S^{implement}$	-	CO_2 emission reduction when a strategy is implemented
$TPP^{initial}$	-	Initial total payback period
TPP^{set}	-	Desired TPP
TPP^{after}	-	Total payback period after SHARPS

Parameter

CC	-	Estimated capital cost (USD/unit)
D	-	Demand
Dt	-	Distance
E	-	Utilised amount of strategy proposed (result in CO_2 emission reduction)
EF	-	Emission factor

H1	-	Header 1
H2	-	Header 2
H1-D	-	Header 1 to demand
H2-D	-	Header 1 to demand
H2-H1	-	Header 2 to Header 1
H1-H2	-	Header 1 to Header 2
P_{CO2}	-	CO_2 purity
R^{ER}	-	Recovery efficiency
S	-	Source
x	-	Consumption activity

Other

CC	-	Composite curve
CCC	-	Cost composite curve
CCS	-	Carbon capture and storage
CCU	-	Carbon capture and utilisation
CCUS	-	Carbon capture, utilisation and storage
CECR	-	Cost effective carbon reduction
CEPA	-	Carbon emission Pinch Analysis
CMH	-	Carbon management hierarchy
CO_2CC	-	Carbon dioxide composite curve
CSCA	-	Carbon storage cascade analysis
CSCC	-	Carbon storage composite curve
CSPO	-	Certified sustainable palm oil
CUM	-	Cumulative
CUS-PTA	-	CO_2 Utilisation and Storage–Problem Table Algorithm
EOR	-	Enhanced oil recovery
EROI	-	Energy return on energy investment
FiT	-	Feed-in-Tariff
GCA	-	Gas cascade analysis
GCC	-	Grand composite curve
GCCA	-	Generic carbon cascade analysis
GHG	-	Greenhouse gas
HEN	-	Heat exchanger network
HI	-	Heat integration
ICO_2R	-	Investment versus CO_2 reduction
LCoE	-	Levelised cost of electricity
LIES	-	Locally integrated energy system
LP	-	Linear programming
MED	-	Ministry of Economic Development
PI	-	Process integration
PTA	-	Problem table algorithm
RCN	-	Resource conservation network
RE	-	Renewable energy
REC	-	Regional energy clustering
RESDC	-	Regional energy surplus deficit curve
RSPO	-	Roundtable on Sustainable Palm Oil
RRMCC	-	Regional resource management composite curve
SDC	-	Source demand curve
SHARPS	-	Systematic hierarchical approach for process screening

SUGCC	-	Site utility grand composite curve
TS	-	Total site
TSCI	-	Total site CO_2 integration
WAMPA	-	Waste management Pinch Analysis

LIST OF SYMBOLS

%	-	Percentage
ΔP_d	-	Pressure drop
°C	-	Degree celcius
D	-	Pipe diameter
$\mathcal{E}$	-	Roughness value
EF	-	Emission factor
E_s	-	Utilised amount
f	-	Friction factor
in	-	Inch
kg	-	Kilogram
km	-	Kilometre
kW	-	Kilowatt
L	-	Pipe length
m	-	Mass flow rate
M	-	Million
m^3	-	Meter cubic
m_n	-	Slope for each strategy
MPa	-	Megapascal
MWh	-	Megawatt hour
Re	-	Reynolds number
t	-	Tonne
TJ	-	Terajoule
y	-	year
Π	-	Pi
ρ	-	Fluid density
Σ	-	Summation

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