SYNTHESIS OF TITANIUM TETRACHLORIDE THROUGH CARBOTHERMAL REDUCTION AND CHLORINATION OF ILMENITE CONCENTRATE

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UNIVERSITI SAINS MALAYSIA

2018

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By

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This thesis submitted in fulfillment of the

requirments for the degree of

Doctor of Philosophy

AUGUST 2018

DEDICATION

To my lovely wife Dr. Mahdieh Malekzadeh

ACKNOWLEDGEMENT

In the name of God; the compassion, the merciful. I would like to express my deepest sincere thanks to my main supervisor, Dr. Sheikh Abdul Rezan Bin Sheikh Abdul Hamid, who has supported me with his guidance, patience and encouragement throughout this thesis. Also, to my co-supervisors Assoc. Prof. Dr. Hashim B. Hussin, Assoc. Prof. Dr. Kamar Shah B. Ariffin and Dr. Norlia Bt. Baharun. The successful completion of this thesis was due to their guidance, constant encouragement, and stimulating discussions throughout the course of this research. I also wish to express my special thanks to my supervisor Prof. Ryosuke O. Suzuki during my internship at Division of Materials Science and Engineering, Faculty of Engineering, Hokkaido University for his kindness and support. I would also like to acknowledge Dr. Sivakumar A/L Ramakrishnan for sharing his knowledge and guidance on modelling of the processes, kindness, encouragements and support for our research group.

This project was made possible by the financial support from Universiti Sains Malaysia (USM). I also gratefully acknowledge the financial support received from Institute of Postgraduate Studies, USM Fellowship, APEX (1002/JHEA/ATSG4001), Ministry of Higher Education (MOHE) of Malaysia through the USM Research University Individual (RUI) grant (No. 1001/PBAHAN/814273).

Further thanks to Dean of School of Materials and Mineral Resources Engineering (SMMRE), Prof. Dr. Zuhailawati Bt. Hussain for her help and support during my studies. Many thanks to Prof. Dr. Ahmad Fauzi Bin Mohd Noor; I could not complete this research without his kind help and support. I would like to extend my appreciation to USM technicians especially Mr. Shahrul, Mr. Kemuridan, Mr. Azrul, Mr. Shafiq, Mr. Helmi and Puan Haslina for their invaluable help and support

for experimental works. Furthermore, the administrative staff of SMMRE, especially Pn. Nur Shalydah Bt. Salleh and Pn. Nor Asmah Bt. Md Nor were very kind and generous, and helped me more than just paperwork. I am also indebted to many people who helped and supported me in completing this research.

Last but not least, the great sacrifices and patience of all my family members, especially my wife who motivated and supported me to complete this PhD thesis, are very much appreciated. Thank you.

Eltefat Ahmadi
August 2018

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Figure 4.65: Photos taken from the digested materials in the progress of production of $TiCl_4$ from ilmenite of Malaysia, (a) Ilmenite, (b) nitrided ilmenite, (c) Fe concentrate, (d) low-Fe $TiO_xC_yN_z$ and (e) chlorination residue. 227

Figure 4.66: Fe and Ti contents of raw ilmenite from Malaysia, reduced and nitrided ilmenite, low-Fe $TiO_xC_yN_z$, Fe concentrate and 238

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LIST OF SYMBOLS

Symbol	Description
ΔG	Gibbs free energy changes
°C	Degree centigrade
%	Percentage
wt%	Weight percent
D	Molecular diffusion coefficient (m^2/s)
g	Gram
L	Litre
K	Kelvin
kJ	Kilo Joule
atm	Atmosphere
kPa	Kilo Pascal
μm	Micrometre
b	Stoichiometric coefficient
C_A	Concentration ($mol.cm^{-3}$)
D	Molecular diffusion coefficient ($m^2.s^{-1}$)
t	Time (minute)
τ	Total conversion time (minute)
k_s	Surface reaction rate constant ($minute^{-1}$)
k_d	External diffusion-controlled rate constant (min^{-1})
k'_d	Internal (pore) diffusion-controlled rate constant (min^{-1})
k_M	Mixed-controlled rate constant(min^{-1})
R_0	Initial radius (cm)

X	Fraction extracted
ρ_{TiN}	Molar density ($mol.cm^{-3}$)
E_a	Apparent activation energy (kJ/mol)
T	Temperature (K)
P	Pressure (bar)
σ_{AB}	Collision diameter, a Lennard-Jones parameter (Angstrom)
Ω_{AB}	Diffusion collision integral, dimensionless
M_A	Molecular weights of $TiCl_4$
M_B	Molecular weights of Cl_2
W_f	Final weight of sample
W_i	Initial weight of sample
f_O	fractions of oxygen
f_C	fractions of carbon
f_N	fractions of nitrogen
$f°_{O,T}$	Total fraction of oxygen
$f°_{o,R}$	Total reducible oxygen
X	Extent of reduction
X_N	Extent of nitridation
ppm	Part per million
A	Activation energy
kt	kilotonnes

LIST OF ABBREVIATIONS

Abbreviation	Description
ADMA	Advanced Materials
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
BET	Brunauer–Emmett–Teller
BJH	Barrett-Joyner-Halenda
CHNS	Carbon Hydrogen Nitrogen Sulphur
CP1	Commercially Pure grade 1
CP2	Commercially Pure grade 2
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTRN	Carbothermal Reduction and Nitridation
CV.	Coefficient of Variance
DOE	Design of Experiment
EAF	Electric Arc Furnace
EARS	Enhanced Acid Regeneration Separation
EDO	Electrochemical Deoxidation
EDX	Energy-Dispersive X-ray Spectroscopy
EMR	Electronically Mediated Reaction
ERMS	Enhanced Roasting and Magnetic Separation
FBR	Fluidized Bed Reactor
FESEM	Field Emission Scanning Electron Microscopy
FFC	Fray-Farthing-Chen
FFD	Full Factorial Design
FT-IR	Fourier Transform Infrared