STUDY ON THE KINETICS OF CATION EXCHANGE RESINS AS CATALYSTS IN FREE FATTY ACID (FFA) ESTERIFICATION OF SIMULATED USED COOKING OIL

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis project and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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LIST OF SYMBOLS

TPA	12-tungstophosphoric acid
H_3PW/ZrO_2	12-tungstophosphoric acid supported on zirconia
Ea	Activation energy
K_A	Adsorption coefficient of FFA
K_B	Adsorption coefficient of methanol
K_C	Adsorption coefficient of esters
K_D	Adsorption coefficient of water
Al	Aluminium
Al_2O_3	Aluminium oxide
Å	Ångstrøm (0.1 nanometre)
C_{AB}	Bulk concentration of limiting reactant
CaO	Calcium oxide
C	Carbon
CO_2	Carbon dioxide
ρ_b	Catalyst density
R_c	Catalyst radius
Cm	Centimetre
Ce	Cerium
Cs	Caesium
R^2	Coefficient of determination
M	Concentration
C_A	Concentration of free fatty acid
C_C	Concentration of esters
C_{HCl}	Concentration of hydrochloric acid
C_B	Concentration of methanol
C_{NaOH}	Concentration of sodium hydroxide
C_V	Concentration of vacant sites on surface
C_D	Concentration of water
C_{li}	Concentration of the limiting reactant in mixture
x	Conversion
cm^3	Cubic centimetre

^oC	Degree celsius
ID	Diameter
D_{eff}	Effective diffusivity
ΔH	Enthalphy
ΔS	Entrophy
K_{eq}	Equilibrium constant
$Fe_2(SO_4)_2/C$	Ferric sulphate on carbon
$C_{NaOH\ final}$	Final concentration of sodium hydroxide
k_f	Forward rate constant
R	Gas constant
g	Gram
h	Hour/hours
HF	Hydrofluoric acid
H	Hydrogen
H^+	Hydrogen ion/ proton
$C_{NaOH\ initial}$	Initial concentration of sodium hydroxide
$V_{initial}$	Initial volume
J	Joule
K	Kelvin
kJ	Kilojoule
kv	Kilovolt
La_2O_3	Lanthanum oxide
$>$	Larger than
$<$	Less than
L	Litre
MnO	Manganese oxide
m_c	Mass of catalyst
K_c	Mass transfer coefficient
C_M	Mears Criterion
Mpa	Megapascal
μm	Micrometre
mg	Milligram
ml	Millilitre

mmol	Millimoles
Mm	Millimetre
mmHg	Millimetre of mercury
min	Minute/minutes
mol	Molarity
Nd_2O_3	Neodymium oxide
NiO	Nickel (II) oxide
N_2	Nitrogen
ppm	Parts per million
%	Percent
H_3PO_4	Phosphoric acid
±	Plus or minus
psi	Pound per square inch
KOH	Potassium hydroxide
A/a	Pre-exponential factor
r_{AD}	Rate of adsorption
r_{DC}	Rate of desorption
r_s	Rate of surface reaction
r_A	Reaction rate
rpm	Revolution per minute
Si	Silica
NaOH	Sodium hydroxide
SiO_2	Silicon dioxide
m^2	Square metre
NH_2SO_3H	Sulfamic acid
$-SO_3H$	Sulfonic group
S	Sulphur
H_2SO_4	Sulphuric acid
SO_2	Sulphuric oxide
SO_4^2	Sulphated
SO_4^2/SnO_2	Sulphated tin oxide
SO_4^{2-}/TiO_2	Sulphated titanium oxide
SO_4^{2-}/ZrO_2	Sulphated zirconium oxide

$Fe(SO_4)_3/C$	Supported ferric sulphate on carbon
T	Temperature
TCD	Thermal conductivity detector
TiO_2	Titanium oxide
C_t	Total concentration of active sites on surface
WO_3	Tunsteng trioxide
vol	Volume
V_{HCl}	Volume of hydrochloric acid
V_{NaOH}	Volume of sodium hydroxide
v/v	Volume per volume
wt. %	Weight percent
w/w	Weight per weight
C_{wp}	Weisz Prater Criterion
Yb_2O_3	Ytterbium (III) oxide
ZnO	Zinc oxide
ZrO_2	Zirconium oxide

LIST OF ABBREVIATIONS

TPA	12-Tungstopphosphoric acid
ASTM	American Society for Testing and Materials
A-SZr	Aerogel sulphated zirconia catalyst
BET	Brunauer-Emmett-Teller
CAHZ	Dealuminated HSZM-5 with citric acid
CHNS	Elemental analysis
CSTR	Continuous stirred tank reactor
DDPO	Deodorisation processes of palm oil
EDX	Energy dispersive x-ray spectroscopy
E-R	Eley-Rideal
FAME	Fatty acid methyl ester
FAU	Faujasite
FESEM	Field emission scanning electron microscopy
FFA	Free fatty acid
FS/OMC	Ferric sulfate supported on ordered mesoporous carbon
FT-IR	Fourier-Transform Infrared Spectroscopy
H	Hydrogen
HPA	Heteropolyacid
HPAs	Heteropolyacids
HZ	HZSM-5 zeolite
IM-1	Intermediate 1
IM-2	Intermediate 2
LA	Lanthanum oxide
L-M	Levenberg-Marquardt
MFI	ZSM-5
MK700	Kaolin waste
LHHW	Langmuir-Hinshelwood-Hougen-Watson
MOR	Mordenite
N	Nitrogen
OBR	Oscillatory baffled reactor
OSHA	Occupational Safety and Health Administration

OVAAT	One-variable-at-a-time
PBR	Packed bed reactor
PFR	Plug flow reactor
PMo	Molybdophosphoric acid
PSD	Particle size distribution
PSS	Polystyrene waste
P-H	Pseudo-homogeneous
R&D	Research and development
RBFA	Rice bran fatty acid
RBO	Rice bran oil
RHC	Rice husk char
S	Sulphur
SCER	Sulfonated cation exchange resins
SEM	Scanning Electron Microscopy
SiW	Tungstosilicic acid
SLO	Sulphated lanthanum oxide
ST-DVB	Styrene and divinyl benzene
SUCO	Simulated used cooking oil
SZ	Sulphated zirconia
TFR	Tubular flow reactor
TiZ	Titania zirconia
TPD	Thermal desorption spectroscopy
TW	Tungstophoric acid
UCO	Used cooking oil
USDA	United States Department of Agriculture
WZ	Tungstated zirconia
X-SZr	Xerogel sulphated zirconia catalyst