# RESEARCH PROJECT REPORT

# MODELING OF LIQUID FUEL PRODUCTION VIA CATALYTIC CRACKING OF PALM OIL USING MCM-41 AS CATALYST

| | |
|---|---|
| No. INDUK | 1463 /13 |
| TGL. TERIMA | 25-3-2013 |
| | FT |
| No. BUKU | FT-K Kur m |
| | |



PROPOSED BY:

| | |
|---|---|
| HENGKY KURNIAWAN | 5203004011 |
| IVAN YARED | 5203004023 |

DEPARTMENT OF CHEMICAL ENGINEERING
FACULTY OF ENGINEERING
WIDYA MANDALA CATHOLIC UNIVERSITY
SURABAYA


2007

# APPROVAL SHEET

The **RESEARCH** entitled :

**Modelling of Liquid Fuel Production Via Catalytic Cracking of Palm Oil Using MCM-41 As Catalyst**

which is prepared and submitted by :

**Name : Hengky Kurniawan**

**NRP : 5203004011**

presented as partial fulfillment of the requirements for ***Sarjana Teknik*** degree at Department of Chemical Engineering, Widya Mandala Catholic University Surabaya, has been approved by examiners and declared acceptable on December 1, 2007

Surabaya, December 1 ,2007

| Supervisor 1 | Supervisor 2 |
|---|---|
| Ir. Suryadi Ismadji, MT, PhD | Ir.Yohanes Sudaryanto, MT |
| NIK.521.93.0198 | NIK.521.89.0151 |

**Board of Examiners**

| Chairman | Secretary |
|---|---|
| Richard R.Gunawan, S.Si, Ph.D | Ir.Yohanes Sudaryanto,MT |
| NIK.521.99.0406 | NIK.521.89.0151 |

| Member | Member |
|---|---|
| Aylianawati, ST, M.Sc, Ph.D | Herman Hidarso, ST, MT |
| NIK.521.96.0242 | NIK.521.95.0221 |

| Dean of Engineering Faculty | Head of Chemical Engineering Department |
|---|---|
| Ir. Kasmadi Sitomi, M.Eng. | Ir. Suryadi Ismadji, MT, PhD |
| NIK.511.89.0154 | NIK.521.93.0198 |

# APPROVAL SHEET

The **RESEARCH** entitled :

**Modelling of Liquid Fuel Production Via Catalytic Cracking of Palm Oil Using MCM-41 As Catalyst**

which is prepared and submitted by :

**Name : Ivan Yared**

**NRP : 5203004023**

presented as partial fulfillment of the requirements for ***Sarjana Teknik*** degree at Department of Chemical Engineering, Widya Mandala Catholic University Surabaya, has been defended before examiners and declared acceptable on December 1, 2007

Surabaya, December 1 ,2007

| Supervisor 1 | Supervisor 2 |
|---|---|
| Ir. Suryadi Ismadji, MT, PhD | Ir. Yohanes Sudaryanto, MT |
| NIK.521.93.0198 | NIK.521.89.0151 |

**Board of Examiners,**

| Chairman | Secretary |
|---|---|
| Richard R.Gunawan Soetanto, D | Ir. Yohanes Sudaryanto, MT |
| NIK.521.99.0406 | NIK.521.89.0151 |

| Member | Member |
|---|---|
| Aylianawati, ST, MSc, Ph.D | Herman Hidarso, ST, MT |
| NIK.521.96.0242 | NIK.521.95.0221 |

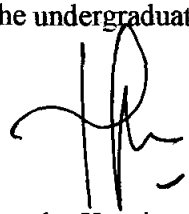
| Dean of Engineering Faculty | Head of Chemical Engineering Department |
|---|---|
| Ir. Kuncoro Sulepu, M.Eng. | Ir. Suryadi Ismadji, MT, PhD |
| NIK.521.89.0154 | NIK.521.93.0198 |

# DECLARATION SHEET

I hereby declare that this research report is my own work and not an act of plagiarism in any part or as a whole, except referenced in the text. If it is known that this research report is not my own work, I am aware and willing to accept the consequences that this research report cannot be used as one of the requirements to achieve Bachelor of Engineering (*Sarjana Teknik*) degree.

Surabaya, December 1st 2007

The undergraduate student



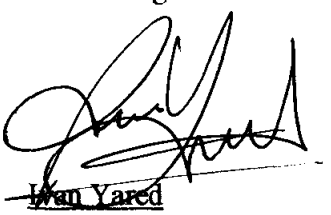
Hengky Kurniawan
NRP. 5203004011

# DECLARATION SHEET

I hereby declare that this research report is my own work and not an act of plagiarism in any part or as a whole, except referenced in the text. If it is known that this research report is not my own work, I am aware and willing to accept the consequences that this research report cannot be used as one of the requirements to achieve Bachelor of Engineering (*Sarjana Teknik*) degree.

Surabaya, December 1st 2007

The undergraduate student



Iwan Yared
NRP. 5203004023

# PREFACE

Praise the God for the guidance and wisdom to let the authors finish this research report entitled *Modelling of Liquid Fuel Production Via Catalytic Cracking of Palm Oil Using MCM-41 As Catalyst.* This research report was made to fulfill one of the requirements needed in achieving Bachelor of Engineering (*Sarjana Teknik*) degree in Chemical Engineering Department, Engineering Faculty, Widya Mandala Surabaya Catholic University.

The authors would like to acknowledge these people for their support and role in the construction of this research report,

1. Suryadi Ismadji, Ir., M.T., Ph.D. and Yohanes Sudaryanto, Ir., M.T as the supervisors of this research.
2. Richard Ruskit Gunawan, S.T., Ph.D, Aylianawati, S.T., M.Sc., Ph.D., and Herman Hindarso, S.T., M.T. as the examiners of this research.
3. Professor Subhash Bhatia and Dr. Farouq Twaiq from Universiti Sains Malaysia for their explanation about their journals.
4. Nico Wibisono, S.T. for his help in preparing the catalyst.
5. Dessy Yovita and Giyanto Wijaya Salim for their help in finishing this research project.
6. Martina, ST. for helping in analyze our product experiments.
7. Other lecturers who helped the author in conducting this research.
8. The authors' parents for giving support and blessing.
9. The authors' colleagues for their support and inspiration.
10. Other persons, who were not mentioned, for their help.

The authors realize that this research report is still imperfect. Therefore, the authors will gladly accept any critics and recommendations to further perfect this report. In the end, the authors hope that this report will be useful for all the readers.

Surabaya, December 1st 2007

The authors

# ABSTRACT

The objective of this study was to determine the reaction kinetics of the catalytic apaacracking of palm oil over MCM-41 as a catalyst at the higher C/O ratio and WHSV. The kinetic values obtained from this study can be used further for industrial purpose.

In this study, palm oil was cracked using MCM-41 as a catalyst in a fixed bed micro-reactor. The experiment was conducted at the atmospheric pressure, with reaction temperature of 623.15 K, 673.15, and 723.15 K, Weight Hourly Space Velocity (WHSV) of 15, 17.5, 20, 22.5, 25, 27.5, and 30 $h^{-1}$, and C/O (catalyst/oil) ratio of 1:32.5. The kinetic model used in this study was the three-lump model developed by Weekman, which involves parallel cracking of palm oil to Organic Liquid Product (OLP) and gas plus coke, with consecutive cracking of the OLP to gas plus coke. The model can represent the experimental data fairly well.

From the study, the rate constant values $k_1$, $k_2$, $k_3$ for reaction temperature of 623.15 K were found to be 9.3964, 1.7581 and 0.4732 $h^{-1}$, respectively. For reaction temperature of 673.15 K, the rate constant values were 20.0346, 3.5761 and 0.5977 $h^{-1}$. For reaction temperature of 723.15 K, the rate constant values were 28.2084, 5.1278 and 0.6639 $h^{-1}$. Using the Arrhenius equation, the activation energy is 41.49, 40.36 and 12.78 kJ/mol for $E_1$, $E_2$, and $E_3$, respectively.

# CONTENTS

Approval Sheet ..... ii

Declaration Sheet ..... iii

Preface ..... iv

Abstract ..... v

Contents ..... vi

List of Figures ..... viii

List of Tables ..... x

Abbreviations ..... xi

Nomenclatures ..... xii

Chapter I. Introduction ..... 1

I.1. Background ..... 1

I.2. Problem Formulation ..... 3

I.3. Aim of The Study ..... 3

I.4. Problem Limitations ..... 4

Chapter II. Literature Review ..... 5

II.1. Palm Oil ..... 5

II.2. Catalytic Cracking of Palm Oil ..... 9

II.3. MCM-41 ..... 12

II.4. Cracking Model ..... 15

Chapter III. Research Methodology ..... 18

III.1. Experimental Design ..... 18

III.2. Process Variables ..... 19

III.2.1. Fixed Variables ..... 19

III.2.2. Dependant Variables ..... 20

III.3. Materials ..... 20

III.3.1. Synthesis of MCM-41 ..... 20

III.3.2. Catalytic Cracking of Palm Oil ..... 21

III.4. Equipments ..... 21

IV.4.1. Synthesis of MCM-41 ..... 21

IV.4.2. Catalytic Cracking of Palm Oil ..... 22

III.5. Experimental methods ..... 24

III.5.1. Material Preparations ..... 24

III.5.1.1. Synthesis of MCM-41 ..... 24

III.5.1.2. Palm Oil Analysis ..... 24

III.5.2. Catalytic Cracking of Palm Oil ..... 25

Chapter IV. Results and Discussion ..... 26

IV.1. Catalytic Cracking of Palm Oil ..... 26

Chapter V. Conclusion ..... 35

Bibliography ..... 36

Appendix A.Composition of Palm Oil ..... 38

Appendix B. Liquid Product ..... 39

Appendix C. Concentration Data for Various WHSV and Temperatures ..... 40

Appendix D.Calculation of Flow Rate of Palm Oil and Maximum Run Time ..... 41

Appendix E.Algorithm of Gauss Jordan Method Using Mathlab 7.1. Program ..... 42

Appendix F.Algorithm of Runge-Kutta Method Using Mathlab 7.1. Program ..... 43

Appendix G. Calculation Method ..... 45

Appendix H. Predicted Concentration Data For Various WHSV and Reaction Temperatures. ..... 56

# LIST OF FIGURES

Figure II.1. Production and Total Consumption Palm Oil in the World....6

Figure II.2. Consumption Palm Oil in the World....6

Figure II.3. Production and Total Consumption Palm Oil in Indonesia....7

Figure II.4. Proposed Reaction path-Way for Cracking of Palm Oil over HZSM-5...12

Figure II.5. SEM Image of The Catalyst....14

Figure II.6. XRD Pattern of The Catalyst....14

Figure II.7. Nitrogen Sorption Isotherm and Pore Size Distribution of the Catalyst...14

Figure II.8. XRD Pattern of MCM-41....14

Figure II.9. Nitrogen Sorption Isotherm of MCM-41....15

Figure II.10. Three-Lump Model....16

Figure III.1. A Set of Catalytic Cracking Apparatus....23

Figure IV.1. Burning of Liquid Product....26

Figure IV.2. Burning of Gas Product....27

Figure IV.3. Concentration of UPO,OLP and Gas+Coke for Various Reaction Temperature and WHSV....28

Figure IV.9. Comparison of Experimental Concentration Yield of UPO, OLP, and Gas+coke....34

Figure G.1. Charts of First Order and Second Order Kinetic for Reaction Temperature of 623.15 K....47

Figure G.2. Charts of First Order and Second Order Kinetic for Reaction Temperature of 673.15 K....48

Figure G.3. Charts of First Order and Second Order Kinetic for Reaction Temperature of 723.15 K....49

Figure G.4. Plot of $C_{OLP}$ and $\tau$ for Different Reaction Temperatures.....51

Figure G.5. Plot of $C_{gas+coke}$ and $\tau$ for Different Reaction Temperatures.....53

Figure G.6. Plot of Arrhenius Equation.....55

# LIST OF TABLES

Table II.1. Production of Oil in The World ..... 5

Table II.2. Fatty Acids Content in Palm Oil ..... 8

Table II.3. Fatty Acids Content in Palm Kernel Oil ..... 8

Table II.4. The Properties of Palm Oil Before and After Purification ..... 9

Table IV.1. Kinetic Constants for Three-Lump Model at Various Reaction Temperatures ..... 30

Table IV.2. Increment of Rate Constants for Different Reaction Temperatures ..... 31

Table IV.3.Comparison of Activation Energies with Gas Oil Cracking from Literatures ..... 31

Table B.1. Liquid Product's Mass for Reaction Temperature of 623.15 K ..... 39

Table B.2. Liquid Product's Mass for Reaction Temperature of 673.15 K ..... 39

Table B.3. Liquid Product's Mass for Reaction Temperature of 723.15 K ..... 39

Table C.1. Concentration Data for Reaction Temperature of 623.15 K ..... 40

Table C.2. Concentration Data for Reaction Temperature of 673.15 K ..... 40

Table C.3. Concentration Data for Reaction Temperature of 723.15 K ..... 40

Table H.1. Predicted Data for Reaction Temperature of 623.15 K ..... 56

Table H.2. Predicted Data for Reaction Temperature of 673.15 K ..... 56

Table H.3. Predicted Data for Reaction Temperature of 723.15 K ..... 56

# ABBREVIATION

UPO = Unconverted Palm Oil

C/O = catalyst to oil weight ratio

OLP = Organic Liquid Product

WHSV = Weight Hourly Space Velocity

# NOMENCLATURES

WHSV = Weight Hourly Space velocity ($h^{-1}$)

$\tau$ = holding time (h)

$C_{OLP}$ = Concentration of organic liquid product (% weight)

$C_P$ = Concentration of unconverted palm oil (% weight)

$C_{gas+coke}$ = Concentration of gas + coke (% weight)

$k_1$ = palm oil cracking rate constant to OLP ($hr^{-1}$)

$k_2$ = palm oil cracking rate constant to gas + coke ($hr^{-1}$)

$k_3$ = OLP cracking rate constant to gas + coke ($hr^{-1}$)

E = activation energy (kJ/mol)

T = temperature (K)

$k_{10}$ = Arrhenius constant for palm oil cracking to OLP ($hr^{-1}$)

$k_{20}$ = Arrhenius constant for palm oil cracking to gas + coke ($hr^{-1}$)

$k_{30}$ = Arrhenius constant for OLP cracking rate constant to gas + coke ($hr^{-1}$)