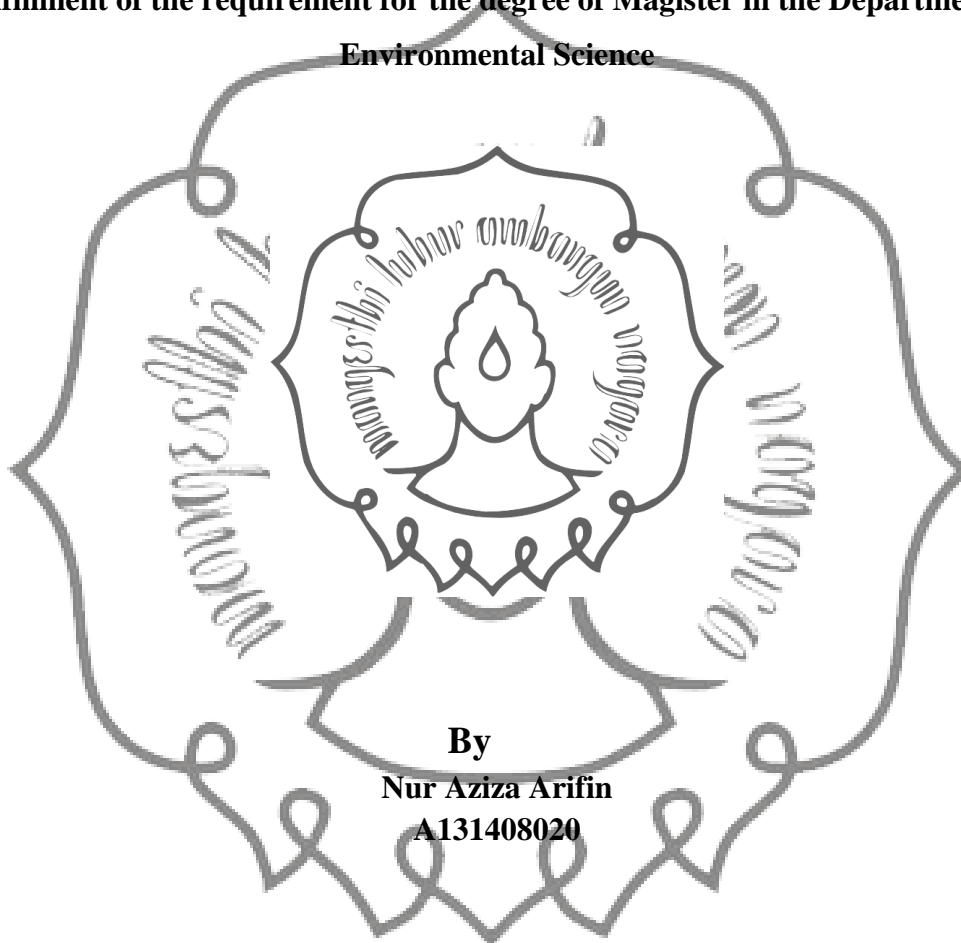


**THE INFLUENCE OF COMPOSITION AND FINAL PYROLYSIS
TEMPERATURE VARIATIONS ON GLOBAL KINETICS OF
COMBUSTION OF SEGREGATED MUNICIPAL SOLID WASTE**

THESIS

Submitted to the Postgraduate Program of Sebelas Maret University in partial
fulfillment of the requirement for the degree of Magister in the Department of
Environmental Science



By

Nur Aziza Arifin

A131408020

**POSTGRADUATE PROGRAM
DEPARTMENT OF ENVIRONMENTAL SCIENCE
SEBELAS MARET UNIVERSITY (UNS)
SURAKARTA**

2016

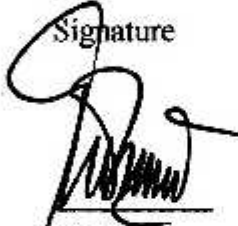


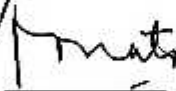
**THE INFLUENCE OF COMPOSITION AND FINAL PYROLYSIS
TEMPERATURE VARIATIONS ON GLOBAL KINETICS OF COMBUSTION
OF SEGREGATED MUNICIPAL SOLID WASTE**

THESIS

**Submitted by
NUR AZIZA ARIFIN
A131408020**

**Has been eligible and approved in the presence of the examiners on the thesis exam
and has fulfilled the qualification on June 27th, 2016**

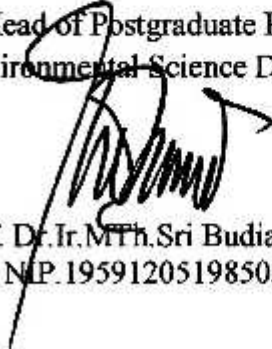
Examiner's committee:

| Title | Name | Signature | Date |
|-----------------------|--|---|----------------|
| President | Prof. Dr.Ir.MTh.Sri Budiastuti, M.Si NIP.195912051985032001 |  | _____ |
| Secretary | Dr. M.Masykuri, M.Si. NIP. 196811241994031001 |  | _____ |
| Examiner's Members | Prof. Dr. Dwi Aries Himawanto, S.T., M.T NIP. 197403262000031001 Dr. Pranoto, M.Sc. NIP. 195410301984031002 |   | _____ _____ |

Approved by


Director of Postgraduate Program

Prof. Dr. M. Furqon Hidayatullah, M.Pd
NIP.196007271987021001

Head of Postgraduate Program
Environmental Science Department

Prof. Dr. Ir. MTh. Sri Budiastuti, M.Si
NIP.195912051985032001

ABSTRACT

Nur Aziza Arifin. A131408020. 2016. "The Influence of Composition and Final Pyrolysis Temperature Variations on Global Kinetics of Combustion of Segregated Municipal Solid Waste". Supervisor I. Prof. Dr. Dwi Aries Himawanto, S.T., M.T., Supervisor II. Dr. Pranoto, M.Sc. Program of Masters studies of Environmental Science, University Sebelas Maret.

The combustion of segregated municipal solid waste (MSW) and the resulted char from the pyrolysis process were investigated in this research. The segregated MSW that was collected and used can be divided into organic and inorganic waste materials. The organic materials were bamboo and banana leaves and the inorganic materials were styrofoam and snack wrappings. The composition ratio of the waste was based on the percentage of weight of each sample. The variation ratio in composition between organic and inorganic materials were 0-100%, 10-90%, 20-80%, 30-70%, 50-50%, 70-30%, 80-20%, 90-10%, 10-90% and 100-0%.

The thermal behavior of the segregated MSW was investigated by thermo gravimetric analysis with mass spectrometry (TGA-MS). For the combustion process the 20 gram samples of raw MSW and char were heated from ambient temperature until the end at a constant heating rate of 15°C/min. For the pyrolysis process the prepared samples of 200gram were heated from ambient temperature until a variance of final pyrolysis temperature of 550°C, 650°C and 750°C at a constant heating rate of 25°C/min.

It was found that the highest activation energy of the raw materials is achieved from sample CC1 (Char with 100% inorganic materials). The activation energy of the raw materials is relatively lower than that of the char. The characteristics of the combustion process of the raw MSW materials in this research are accordance to the theory of solid fuels. The decomposition of hemicellulose started at a higher temperature for the combustion of the raw materials than that if the combustion of char MSW. The breakdown of cellulose also started at a higher temperature and finished at a lower temperature for the combustion of char. It takes more energy to burn the maximum amount of MSW (Tpeak-maximum mass loss) in the samples with a higher amount of inorganic material in the raw waste material samples. The higher the final pyrolysis temperature, the lower the calorific value of char. The calorific value gradually increases with the amount of inorganic materials.

Key words: *Thermo gravimetric analysis, Municipal Solid Waste, Combustion, Pyrolysis, Char.*

ABSTRAK

Nur Aziza Arifin. A131408020. 2016. "Pengaruh Variasi Komposisi dan Suhu Akhir Pirolisis pada Global Kinetika Pembakaran Sampah Kota Terseleksi". Pembimbing I. Prof. Dr. Dwi Aries Himawanto, S.T., M.T., Pembimbing II. Dr. Pranoto, M.Sc. Program Studi Magister Ilmu Lingkungan, University Sebelas Maret.

Pembakaran sampah kota padat terpilih (MSW) dan char dihasilkan dari proses pirolisis diteliti dalam penelitian ini. Sampah kota terpilih yang dikumpulkan dan digunakan dapat dibagi bahan sampah organik dan anorganik. Bahan organik adalah bambu dan daun pisang dan bahan anorganik adalah styrofoam dan pembungkus kemasan. Perbandingan komposisi limbah didasarkan pada persentase bobot masing-masing sampel. Rasio variasi dalam komposisi antara bahan organik dan anorganik adalah 0-100%, 10-90%, 20-80%, 30-70%, 50-50%, 70-30%, 80-20%, 90-10%, 10-90% dan 100-0%.

Termal karakteristik sampah kota terseleksi diteliti dengan thermo analisis gravimetri- massa spektrometri (TGA-MS). Untuk proses pembakaran sampel yang digunakan adalah sampah kota padat baku dan char sebesar 20 gram dan dipanaskan mulai dari suhu ambien sampai akhir dengan laju pemanasan konstan 15°C/menit. Untuk proses pirolisis sampel disiapkan sebesar 200gram dan dipanaskan mulai dari suhu ambien sampai varians suhu pirolisis akhir 550°C, 650°C dan 750°C dengan laju pemanasan konstan 25°C/menit.

Dalam penelitian ini telah ditemukan bahwa energi aktivasi tertinggi dari bahan baku dicapai dari sampel CC1 (Char dengan bahan anorganik 100%). Energi aktivasi dari bahan baku relatif lebih rendah dibandingkan dengan char. Karakteristik pembakaran bahan baku dalam penelitian ini adalah sesuai dengan teori bahan bakar padat. Dekomposisi hemiselulosa mulai pada suhu yang lebih tinggi untuk pembakaran bahan baku dari pada pembakaran char. Pemecahan selulosa juga mulai pada suhu yang lebih tinggi dan selesai pada suhu yang lebih rendah untuk pembakaran char. Dibutuhkan lebih banyak energi untuk membakar jumlah maksimum sampah kota (T_{peak}- kehilangan massa maksimum) dalam sampel dengan jumlah yang lebih tinggi dari bahan anorganik dalam sampel bahan limbah baku. Semakin tinggi akhir suhu pirolisis, semakin rendah nilai kalori char. Nilai kalor secara bertahap meningkat dengan jumlah bahan anorganik.


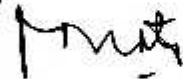
Kata kunci: *Thermo analisis gravimetri, Sampah kota padat terseleksi, Pembakaran, Pirolisis, Char.*

AGREEMENT

**THE INFLUENCE OF COMPOSITION AND FINAL PYROLYSIS
TEMPERATURE VARIATIONS ON GLOBAL KINETICS OF COMBUSTION
OF SEGREGATED MUNICIPAL SOLID WASTE**

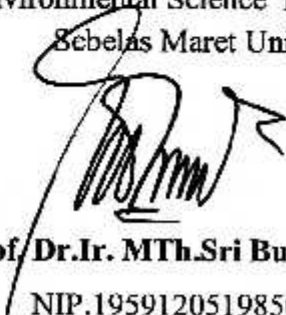
THESIS

**Submitted by
Nur Aziza Arifin
A131408020**

| Supervisor committee | Name | Signature | Date |
|---------------------------------|---|---|-------------|
| Supervisor I | Prof. Dr. Dwi Ariès Himawanto, S.T., M.T NIP. 197403262000031001 |  | |
| Supervisor II | Dr. Pranoto, M.Sc. NIP. 195410301984031002 |  | |

**Has been declared eligible and approved
on this date of June 27th 2016**

**Head of the Postgraduate Program
Environmental Science Masters Study
Sebelas Maret University**


**Prof. Dr. Ir. MTh. Sri Budiastuti, M.Si
NIP. 1959120519850320012**

BIODATA

- a. Name : Nur Aziza Arifin
- b. Birth place and date : Marowijne, 5 oktober 1986
- c. Home adress : Zuurstof straat 24. Tourtonne 5. Paramaribo. Suriname.

South America

- d. Last education history :

| No. | Institute | Field | Year | Degree |
|-----|-------------------------------------|---|------|--------|
| 1. | Anton de Kom University of Suriname | Environmental Science Environmental Technology | 2011 | B.Sc. |

- e. Scientific work :

| No. | Title | Publisher/ Scientific Forum | Tahun |
|-----|--|---|-------|
| 1. | The effectiveness of the vetiver system as a purification technique in mercury pollution | Thesis bachelor studies/ Anton de Kom University of Suriname | 2013 |

ACKNOWLEDGEMENT

Assalamu'alaikum Warohmatulohi Wabarokatu.

First and above all, I praise ALLAH, the almighty for providing me this opportunity and granting me the capability to proceed successfully. This thesis appears in its current form due to the assistance and guidance of several people. I would therefore like to offer my sincere gratitude to all who have supported me throughout the course of this Master degree in environmental studies. I am very grateful for the aspiring guidance and invaluable constructive criticism during the research.

Mr. Prof. Dr. Dwi Aries Himawanto, S.T., M.T, my first supervisor, my cordial thanks for accepting me to participate in your project as a Masters student, your warm encouragement, thoughtful guidance, critical comments, and correction of the thesis.

I want to express my deep thanks to my esteemed second supervisor, Mr. Dr. Pranoto M.Sc. for the trust and support, the insightful discussion, offering valuable advice during the whole period of the study, and especially for your patience and guidance during the writing process.

Besides my supervisors, I would like to my examiner Dr. M. Masykuri, M.Sc. for his insightful comments and encouragement, but also for the hard questions which incited me to widen my research from various perspectives.

I would like to thank the Head of Masters studies of Environmental Science Department, Prof. Dr. Mth. Budiastuti M.Si, Head of the Doctors studies of Environmental Science Department, Dr. Prabang Setyono, mbak Dina and mas Diki, for their readiness to assist and guide whenever I needed their services.

A special thanks goes to the Indonesian government, *Kemitraan Negara Berkembang* (KNB) Scholarship Program for giving me the opportunity to study in Indonesia, Mr. Prof. Dr. H. Ravik Karsidi. M.S., the rector of University Sebelas Maret Surakarta and Mr. Prof. Dr. M. Furqon Hidayatullah, M.Pd, director of Post Graduate studies of Universitas Sebelas Maret Surakarta for giving me the opportunity to study at one of the best Universities in Indonesia.

I also thank the head of material laboratory of Faculty Mechanical Engineering and my fellow laboratory friends, Abdullah Salih, Murnanda Zaesy Saputra, Riski Kurniawan and Zuhdy Ilham Utama, for sharing their knowledge and support during the restless times in the laboratory.

I owe my gratitude to my classmates especially Arlindo Macie (from Mozambique), Willie Suzuki (from PNG), and my fellow Indonesian classmates especially Angreini Beta, mas Subardi and mbak Ayu that have helped in many ways especially in translating and explaining things during the master's program study.

I am grateful for having Mukhriddin Khosimov, Ahmad Algoul, Pham Ha Xuyen, Khaled Almgadmi and Roxanne Karta as my closest friends who became my family in Indonesia. Thank you for listening to my complaints and motivating me in the most profound way.

Last but not least, I would like to thank my wonderful parents Ali Arifin and Fatmawati Dekok, my brother Taufieq, my sister Afifa and her family, as well as my dear friend Silma Kasto for their loving support and motivation. Although we were so far apart, the daily video calls and chats provided a good emotional atmosphere in these three difficult years.

May Allah s.w.t. give all of you the best in return for all the love and support.

Wassalamu alaikum warohmatullohi wabarokatu.

Surakarta, June 27th, 2016

Nur Aziza Arifin

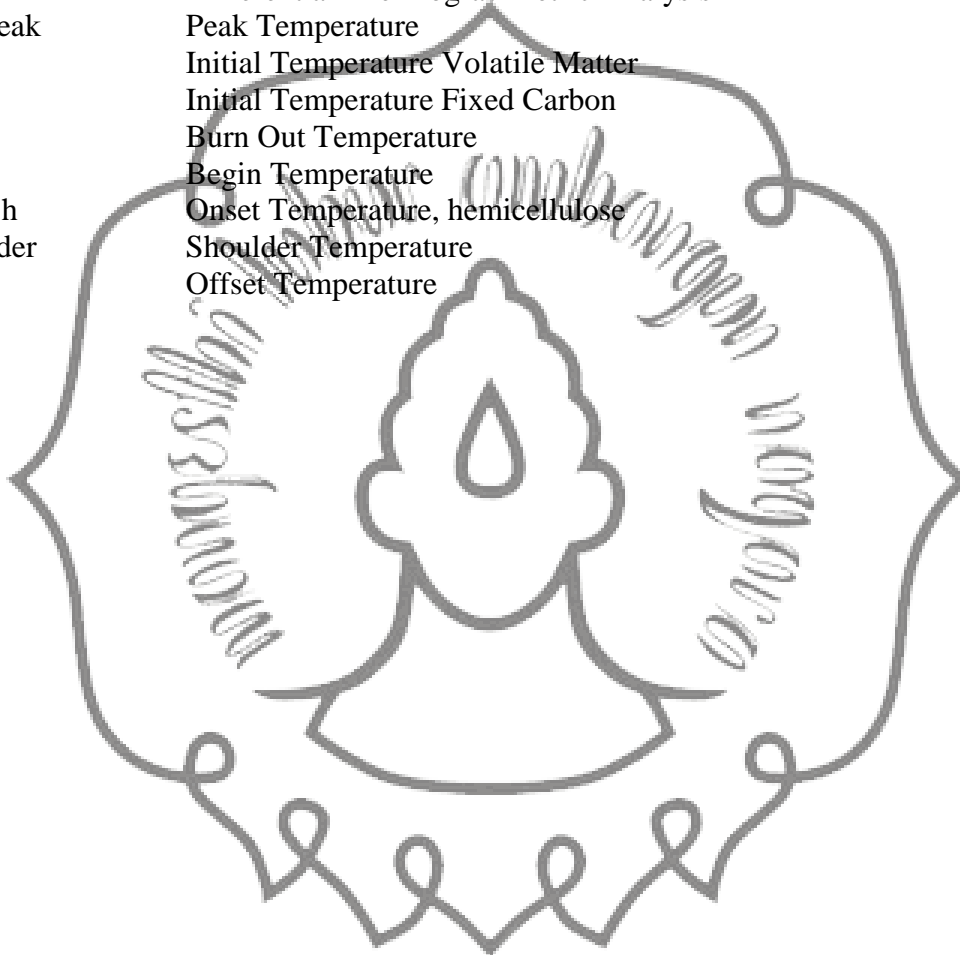
CONTENTS

| | |
|---|-------------------------------------|
| AGREEMENT | Error! Bookmark not defined. |
| STATEMENT OF ORIGINALITY AND PUBLICATION..... | Error! Bookmark not defined. |
| BIODATA | Error! Bookmark not defined. |
| ACKNOWLEDGEMENT..... | Error! Bookmark not defined. |
| ABSTRACT | Error! Bookmark not defined. |
| ABSTRAK | Error! Bookmark not defined. |
| CONTENTS | ix |
| LIST OF ABBREVIATIONS | xi |
| LIST OF TABLES | xii |
| LIST OF FIGURES..... | xiii |
| LIST OF GRAPHS..... | xiv |
| LIST OF PHOTOS..... | xv |
| LIST OF APPENDICES | xvi |
| CHAPTER I INTRODUCTION | Error! Bookmark not defined. |
| A. Background..... | Error! Bookmark not defined. |
| B. Problem statement..... | Error! Bookmark not defined. |
| C. Purpose of this research..... | Error! Bookmark not defined. |
| D. Benefits of this research | Error! Bookmark not defined. |
| E. Significance of the research..... | Error! Bookmark not defined. |
| CHAPTER II THEORETICAL BASIS | Error! Bookmark not defined. |
| A. Literature review..... | Error! Bookmark not defined. |
| 1. Municipal solid waste in Surakarta..... | Error! Bookmark not defined. |
| 2. Pyrolysis..... | Error! Bookmark not defined. |
| 3. Combustion of MSW | Error! Bookmark not defined. |
| 4. Global kinetics analysis of combustion | Error! Bookmark not defined. |
| B. Relevant researches | Error! Bookmark not defined. |
| C. Research Framework | Error! Bookmark not defined. |
| CHAPTER III METHODOLOGY | Error! Bookmark not defined. |

| | |
|---|-------------------------------------|
| A. Location site | Error! Bookmark not defined. |
| B. Time of the study | Error! Bookmark not defined. |
| C. Governance Research | Error! Bookmark not defined. |
| 1. Type of Research | Error! Bookmark not defined. |
| 2. Research Design | Error! Bookmark not defined. |
| 3. Research Materials | Error! Bookmark not defined. |
| 4. Sample of the research | Error! Bookmark not defined. |
| 5. Variables of this research | Error! Bookmark not defined. |
| 6. Data collection procedure | Error! Bookmark not defined. |
| 7. Data analysis procedure | Error! Bookmark not defined. |
| CHAPTER IV RESULTS AND DISCUSSION | Error! Bookmark not defined. |
| A. TGA-MS analysis | Error! Bookmark not defined. |
| B. Activation energy | Error! Bookmark not defined. |
| C. Calorific value analysis | Error! Bookmark not defined. |
| D. Environmental principles | Error! Bookmark not defined. |
| CHAPTER V CONCLUSIONS AND RECOMMENDATIONS | Error! Bookmark not defined. |
| A. Conclusions | Error! Bookmark not defined. |
| B. Recommendations | Error! Bookmark not defined. |
| REFERENCES | Error! Bookmark not defined. |
| APPENDIX | Error! Bookmark not defined. |

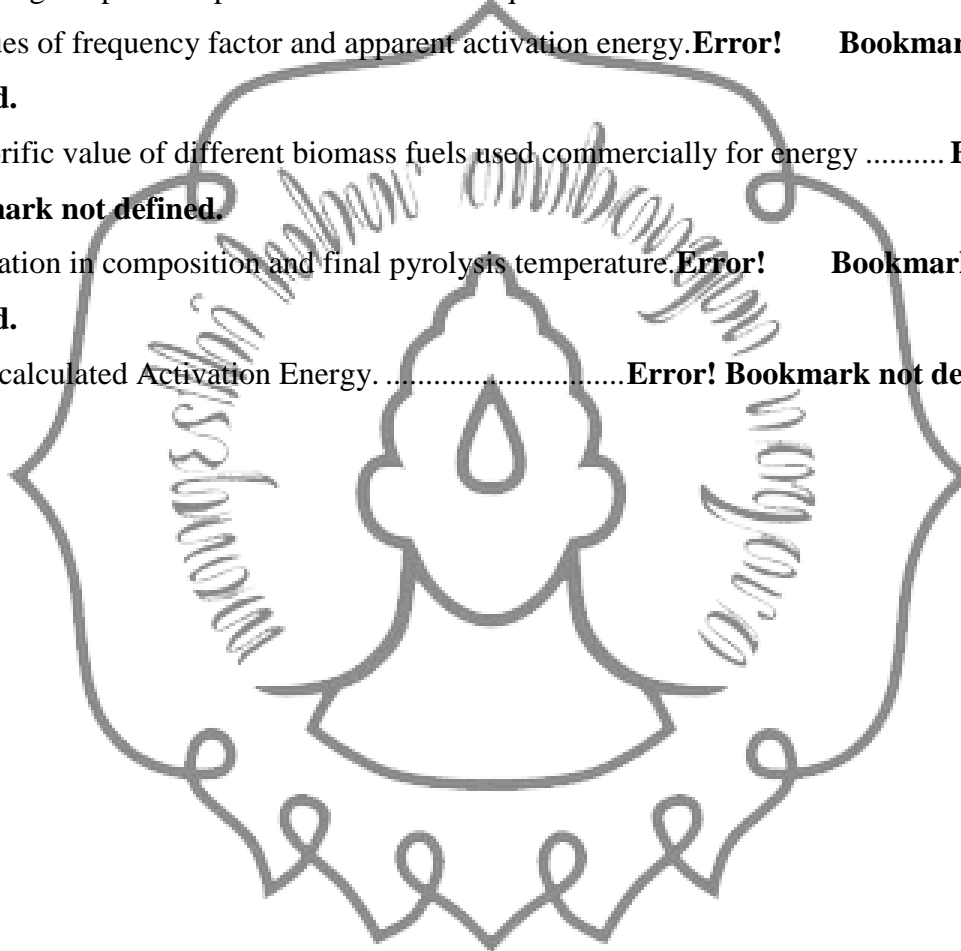
LIST OF ABBREVIATIONS

| | |
|-----------|---|
| MSW | Municipal Solid Waste |
| TPA | <i>Tempat Pemrosesan Akhir</i> / Last Dumping Place |
| TPS | <i>Tempat Pembuangan Sementara</i> / Temporary disposal Place |
| DKP | Dinas Kebersihan dan Pertamanan kota Surakarta |
| DPP | Dinas Pengelolaan Pasar |
| TGA | Thermo gravimetric analysis |
| DTG | Differential Thermogravimetric Analysis |
| PT/ Tpeak | Peak Temperature |
| ITVM | Initial Temperature Volatile Matter |
| ITFC | Initial Temperature Fixed Carbon |
| BT | Burn Out Temperature |
| Tbegin | Begin Temperature |
| Tonset,h | Onset Temperature, hemicellulose |
| Tshoulder | Shoulder Temperature |
| Toffset | Offset Temperature |



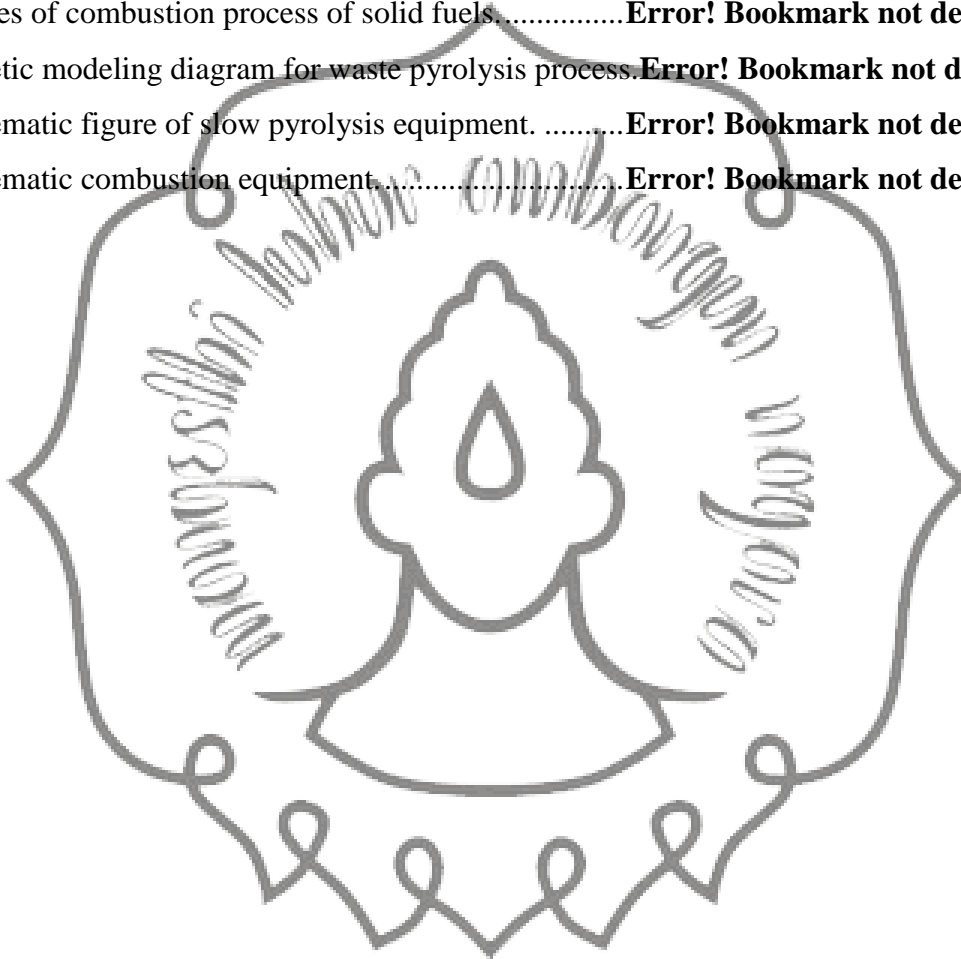
LIST OF TABLES

| Table | Page |
|--|------------------------------|
| 1: Waste volume at TPA "Putri Cempo Mojosongo" year 2012. Error! | Bookmark not defined. |
| 2: Waste composition in year 2006 until 2009. Error! | Bookmark not defined. |
| 3: Burning profiles of the raw materials. Error! | Bookmark not defined. |
| 4: Burning temperature profiles of the char briquettes.... Error! | Bookmark not defined. |
| 5: Values of frequency factor and apparent activation energy. Error! | Bookmark not defined. |
| 6: Calorific value of different biomass fuels used commercially for energy Error! | Bookmark not defined. |
| 7: Variation in composition and final pyrolysis temperature. Error! | Bookmark not defined. |
| 8: The calculated Activation Energy. Error! | Bookmark not defined. |



LIST OF FIGURES

| Figure | Page |
|--|-------------------------------------|
| 1: Stages of combustion process of solid fuels..... | Error! Bookmark not defined. |
| 2: Kinetic modeling diagram for waste pyrolysis process. | Error! Bookmark not defined. |
| 3: Schematic figure of slow pyrolysis equipment. | Error! Bookmark not defined. |
| 4: Schematic combustion equipment..... | Error! Bookmark not defined. |



LIST OF GRAPHS

| Graph | Page |
|--|-------------------------------------|
| 1: Amount of waste collected at the last dumping site Putri Cempo. | Error! Bookmark not defined. |
| 2: Waste production per day in ton in Surakarta. | Error! Bookmark not defined. |
| 3: Combustion characteristics of bamboo briquette. | Error! Bookmark not defined. |
| 4: Combustion characteristics of banana leaves briquette. | Error! Bookmark not defined. |
| 5: Combustion characteristics of snack wrap briquette. . | Error! Bookmark not defined. |
| 6: Combustion characteristics of 70% wt. of the organic briquette. | Error! Bookmark not defined. |
| 7: Combustion profile of 0% organic materials. | Error! Bookmark not defined. |
| 8: Combustion profile of 10% organic materials. | Error! Bookmark not defined. |
| 9: Combustion profile of 20% organic materials. | Error! Bookmark not defined. |
| 10: Combustion profile of 70% organic materials..... | Error! Bookmark not defined. |
| 11: Combustion profile of 100% organic materials..... | Error! Bookmark not defined. |
| 12: Combustion profile of raw materials..... | Error! Bookmark not defined. |
| 13: Decomposition profile of 0% organic materials..... | Error! Bookmark not defined. |
| 14: Decomposition profile of 10% organic materials..... | Error! Bookmark not defined. |
| 15: Decomposition profile of 20% organic materials..... | Error! Bookmark not defined. |
| 16: Decomposition profile of 30% organic materials..... | Error! Bookmark not defined. |
| 17: Decomposition profile of 50% organic materials..... | Error! Bookmark not defined. |
| 18: Decomposition profile of 70% organic materials..... | Error! Bookmark not defined. |
| 19: Decomposition profile of 80% organic materials..... | Error! Bookmark not defined. |
| 20: Decomposition profile of 90% organic materials..... | Error! Bookmark not defined. |
| 21: Decomposition profile of 100% organic materials.... | Error! Bookmark not defined. |

- 22: Activation energy.**Error! Bookmark not defined.**
- 23: Calorific values of the different compositions of char and raw materials..... **Error! Bookmark not defined.**

LIST OF PHOTOS

| Photo | Page |
|--|-------------------------------------|
| 1: Front side of the crusher. | Error! Bookmark not defined. |
| 2: Back side of the crusher (engine). | Error! Bookmark not defined. |
| 3: 20 mesh filter. | Error! Bookmark not defined. |
| 4: The inside of the crusher. | Error! Bookmark not defined. |
| 5: Digital scale. | Error! Bookmark not defined. |
| 6: Thermo couple. | Error! Bookmark not defined. |
| 7: During one of the samples undergoing the combustion process. | Error! Bookmark not defined. |
| 8: Styrofoam waste. | Error! Bookmark not defined. |
| 9: Snack wrapping waste. | Error! Bookmark not defined. |
| 10: Bamboo waste. | Error! Bookmark not defined. |
| 11: Banana leaves waste. | Error! Bookmark not defined. |
| 12: Crushed raw materials in size 20 mesh from left to right: banana leaves, | Error! Bookmark not defined. |



LIST OF APPENDICES

| Appendix | Page |
|---|-------------------------------------|
| 1: TG and DTG graphs of the samples..... | Error! Bookmark not defined. |
| 2: Summeryzed combustion characteristics of MSW and char..... | Error! Bookmark not defined. |
| 3: Decomposition of biomass..... | Error! Bookmark not defined. |
| 4: Summarized decomposition temperature profile of biomass..... | Error! Bookmark not defined. |
| 5: Logarithm graphs of the weight reduction against 1/T..... | Error! Bookmark not defined. |
| 6: Furnace B3 by Prof.Dr.Ir. Herman Johannes | Error! Bookmark not defined. |