# EFFECT OF PARTICLE SIZE AND SECONDARY AIR FOR PARTICULATE BIOMASS COMBUSTION IN A BUBBLING FLUIDIZED BED REACTOR

G.G.S.N. Silva

(159265H)

Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree Master of Science

Department of Chemical and Process Engineering

University of Moratuwa

Sri Lanka

December 2019

**DECLARATION**

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Signature: …… Date: ……



Signature: …… Date: ……

I have supervised and accepted this thesis/ dissertation for the award of the degree.

Signature of Supervisor: …….. Date: ……

Prof. M. Narayana

Senior Lecturer

Department of Chemical and Process Engineering

University of Moratuwa

# ABSTRACT

Biomass combustion is used as basic technology to generate heat by humans for millennia. With the incremental needs of modern man, biomass combustion still plays a major role in heat and power generation. In Sri Lankan context, biomass combustion is extensively used in manufacturing industries for boilers, furnaces, dryers, etc. Even though biomass is abundantly available as an energy source in Sri Lanka, industrial biomass combustion systems are operating under very low efficiencies. Operating these industrial combustion systems in an optimum manner will help in numerous ways to industries, environment and society.

In this study, particulate biomass combustion in a bubbling fluidized bed combustor model is used to evaluate optimum secondary air flow rate rates and particle sizes. First Proximity of particulate biomass (saw dust) was conducted to find out moisture and volatile content, then sieve analysis was conducted to segregate and name the particle sizes. Different particle sizes were fluidized using measured primary air flow and combusted under varied secondary air flow rates and obtained maximum temperature achievement in three distinct locations (top, middle and bottom) in the fluidized bed reactor by using installed temperature transducers. Secondary air flow rates and temperature results were tabulated for each particle sizes to analyze temperature variation. Matlab CFTool feature was used to generate surface fits for all three location (top, middle and bottom) temperature variation against particle size and secondary air flow rates. After evaluation results and surface fits, Optimum operating secondary air flow rates and particles sizes were identified for used lab scale bubbling fluidized bed combustor. Recommendations were suggested for industrial scale particulate biomass combustion systems such as boilers, furnaces, etc. for optimum operation based on lab scale system results.



Key words – particulate biomass combustion, optimum combustion, fluidized bed combustion

**ACKNOWLEDGMENT**

Completion of this thesis has been one of the most significant academic challenges I have ever had encounter. Without the support, patience and guidance of the following people, this task would not have been accomplished.

Guidance and advices of Prof. M.Narayana were helped me to carry out the research works from the beginning. I'm thankful to my supervisor Prof. M.Narayana for giving me the fullest support and courtesy throughout the research work.

I am grateful to all the academic staff of M.Sc in Sustainable process engineering course, Department of chemical and process engineering, University of Moratuwa. I should thank Prof. P.G. Rathnasiri, Former Head of department of Chemical and process engineering, University of Moratuwa and Prof. M.Narayana, Course coordinator for initiating M.Sc in Sustainable process engineering course.

I wish to extend my thanks to Mr. Chathuranga Wickramasinghe, Lecture (Contract) for his support and non-academic staff of department of chemical and process engineering for support during practical works.

I would like thank Mr.Hasitha Perera, Mr.Dasith Wijesekara, Mr.Niranjan Rathnayake, Mr.Tissa Geeganage, and all the colleagues of M.Sc in Sustainable process engineering course of 2015/2016.

Finally, I would like to extend my gratitude to my parents and beloved wife for encouraging me to complete research works.

# TABLE OF CONTENTS

DECLARATION ..... i
ABSTRACT ..... ii
ACKNOWLEDGMENT ..... iii
TABLE OF CONTENTS ..... iv
LIST OF FIGURES ..... v
LIST OF TABLES ..... v
1. INTRODUCTION ..... 1
1.2. Biomass ..... 1
1.3. Combustion ..... 2
1.4. Main reactions of biomass combustion process ..... 4
1.5. Biomass Combustion Systems ..... 5
2. RESEARCH GAP IDENTIFICATION AND COMPARISON ..... 6
3. OBJECTIVES ..... 6
4. APPARATUS ..... 7
5. METHODOLOGY ..... 10
5.1. Combustor assembly diagram and details ..... 10
5.2. Proximate Analysis ..... 11
5.3. Sieve analysis ..... 11
5.4. Fluidizing the bed ..... 12
5.5. Combustion inside the reactor ..... 12
5.6. Obtaining Readings ..... 12
5.7. Analyzing Readings ..... 13
6. PRACTICE LIMITATIONS AND POSSIBLE ERRORS ..... 14
7. RESULTS ..... 15
7.1. Images of used particle sizes ..... 17
7.2. Results ..... 19
7.3. Results Analysis ..... 24
7.4. Temperature variation with secondary air flow rate ..... 25
8. DISCUSSION ..... 35
8.1. Top position temperature variation ..... 35
8.2. Middle position temperature variation ..... 35
10. REFERENCES ..... 39

# LIST OF FIGURES

Figure 4.1- Fluidized bed combustor apparatus ..... 7
Figure 4.2- Blower used in Fluidized bed apparatus ..... 8
Figure 4.3 - Fluidized bed combustor (Front/End/Plan elevations and isometric view) ..... 9
Figure 5.1- Schematic Diagram of Combustor Assembly ..... 10
Figure 7.1 - Particle size -1 ..... 17
Figure 7.2 - Particle size -2 ..... 17
Figure 7.3-Particle size -3 ..... 18
Figure 7.4-Particle size - 4 ..... 18
Figure 7.5- Graph for Temperature variation with secondary air flow rate of particle size-1 ..... 27
Figure 7.6 -Graph for Temperature variation with secondary air flow rate of particle size-2 ..... 27
Figure 7.7- Graph for Temperature variation with secondary air flow rate of particle size-3 ..... 28
Figure 7.8- Graph for Temperature variation with secondary air flow rate of particle size-4 ..... 28
Figure 7.9- 3D Graph for top position temperature variation with secondary air flow rate and particle size ..... 29
Figure 7.10-3D Graph for middle position temperature variation with secondary air flow rate and particle size ..... 31
Figure 7.11- 3D Graph for bottom position temperature variation with secondary air flow rate and particle size ..... 33

# LIST OF TABLES

Table 1.1- Main reactions of biomass combustion ..... 4
Table 5.1- Sieve analysis results ..... 12
Table 7.1- Dimensions of blower air intake points and biomass bed ..... 15
Table 7.2- Particle sizing details ..... 16
Table 7.3- Results of particle size 1 ..... 20
Table 7.4- Results of particle size 2 ..... 21
Table 7.5- Results of particle size 3 ..... 22
Table 7.6- Results of particle size 4 ..... 23
Table 7.7-Temperature variation with secondary air flow rate for particle size 1 ..... 25
Table 7.8-Temperature variation with secondary air flow rate for particle size 2 ..... 25
Table 7.9-Temperature variation with secondary air flow rate for particle size 3 ..... 26
Table 7.10-Temperature variation with secondary air flow rate for particle size 4 ..... 26