Kinetic Modeling of Tar Formation in an Updraft Biomass Gasifier

G.K.M. JAYATHILAKE

(159254A)

Degree of Master of Science in Sustainable Process Engineering

Department of Chemical and Process Engineering

University of Moratuwa Sri Lanka

June 2020

DECLARATION OF THE CANDIDATE AND SUPERVISOR

"I declare that this is my own work and this thesis 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.

Also, I hereby grant to university of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in the future works."

…………………………   ………………………..

Signature   Date

The above candidate has carried out research for the Master Dissertation under my supervision.

……………………………   ……………………….

Signature of the supervisor   Date

Dr. Duleeka Gunarathne

Senior Lecturer Grade II

ABSTRACT

As the depreciation of the fossil fuels in the world, it is obligatory to discover new fuels to the highly industrialized society. With increasing requirements of the energy, it is globally focused on the use of renewable energy. Biomass can be used as an alternative energy source to replace fossil fuels, which contribute to the greenhouse gas emission. Therefore, biomass is a major renewable energy source as of today.

Nowadays, converting biomass into biofuel is a major goal. So, the gasification process can be used as such an effective way to convert biomass into syngas. Even if the major goal of the gasification is to produce syngas such as H_2, CO, intermittently, many byproducts are generated such as NO_x, SO_2, fly ash and tar. The formation of tar in the gasifier is a problematic situation. The formation of tar mainly depends on temperature, residence time, type of biomass and gasifying medium.

Modeling is an effective method to optimize the gasifier operation. Also, it can be used to determine the relationship between operational parameter limits and explain trends in output products. By using Aspen Plus process simulation tool, a kinetic model was developed to predict the tar formation of updraft gasifier considering the main chemical phenomena biomass pyrolysis, reduction and combustion. The results were compared with the experimental data from the literature to validate the model. According to the developed model, the tar content and the composition could be estimated with respect to the equivalence ratio (ER) and pyrolysis zone bed height. When the ER is increasing the formation of tar is trending to decrease. The pyrolysis zone bed height beyond 1.3 cm does not show a significant impact on the tar content.

It is possible to use the developed model to minimize tar content by operating at a suitable temperature (by controlling the ER) and by keeping an applicable residence time (by maintaining a suitable bed height). Further, this model can be used to optimize the tar formation with different biomass types and gasifying mediums when the temperature profile of the gasifier is available.

Keywords: Biomass, Updraft Gasifier, Tar, Kinetic Modeling

NOMENCLATURE

Abbreviation	Description
ER	Equivalence Ratio
PFR	Plug Flow Reactor

Symbol	Description
$C_7H_8O_2$	Guaiacol
$C_8H_8O_3$	Vanillin
C_6H_6O	Phenol
$C_7H_6O_2$	Salicylaldehyde
$C_6H_6O_2$	Catechol
C_7H_8O	o-Cresol
$C_{10}H_8$	Naphthalene
$C_{14}H_{10}$	Phenanthrene
C_6H_6	Benzene
C_5H_6	Cyclopentadiene
C_9H_8	Indene
C	Concentration (mol/m^3)
k	Reaction rate constant (1/s)
r	Reaction rate (mol/m^{3}s)
R	Universal gas constant (J/mol K)
T	Temperature (K)

ACKNOWLEDGEMENTS

I am very grateful to my supervisor Dr. Duleeka Gunarathne, Senior Lecture, Department of Chemical and Process Engineering, University of Moratuwa, for the enormous support and guidance from the initiation to the end of my research work. She always encouraged me throughout the work and guided me to get a fruitful output.

My sincere thanks also go to Prof. Shantha Walpalage Head of the Department of Chemical and Process Engineering, University of Moratuwa.

My special thanks go to Ms. Udya Devaraja, who engaging MPhil in Chemical and Process Engineering, University of Moratuwa, for guiding me to get knowledge about Aspen Plus and for her enormous support given throughout the research to fulfill this work successfully.

My immense gratitude goes to my loving parents for guiding me to face all the challenges in the life and for their encouraging words in every down step and also my younger brother who always keeps in touch with me when I was down.

And also, I want to thank Mr. Roshan Nirmal and my working place staff for making their valuable time for me when I was busy with my research.

Table of Contents

List of Tables

List of Figures

List of Equations