Development of computer aided modelling and optimization of microwave pyrolysis of biomass by using aspen plus

M Dineshkumar, Banagiri Shrikar, Anand Ramanathan*

Department of Mechanical Engineering,
National Institute of Technology, Tiruchirappalli-620 015, India.
*Corresponding Author. Tel: (0431) 2503423, Fax: (0431) 250 0133,
E-mail: anandachu@nitt.edu

Abstract. Biomass energy is nowadays recognized as a potential source which constitutes the main portion of expected renewable energy supplies in the future. Biomass resources such as municipal solid waste, agricultural residue food processing industry waste, energy crops are a common type of renewable energy source and it help to produce energy, chemicals, and fuels. The useful energy recovered from biomass can be effectively utilized by a bio-energy conversion technique known as pyrolysis. Pyrolysis is considered as a kind of thermo-chemical conversion technique of waste material in the inert atmosphere to harvest biochar, syn-gas and bio fuel. Bio fuel harvest from forestry biomass through the microwave pyrolysis technology has been significantly attracting attention in the renewable energy sector over recent years. This is because of fact that microwave pyrolysis can possibly reduce greenhouse gases and contribute to energy security. A simulation model of pyrolysis process is developed by using a software called advanced system for process engineering it is basically a simulation tool for computer-aided energy modelling. This software is used to optimize and analyse the efficiency of the process involved in pyrolysis and to increase the output product yield such as bio-oil, syn-gas, and biochar with respect to the function of input parameters such as pyrolysis temperature and physio-chemical character of the biomasses. The ASPEN PLUS simulation is carried out using four different variety of biomasses namely Acacia Nilotica, Calophyllum inophyllum seed, rice husk, and Bael shell. The simulation results demonstrate that Calophyllum inophyllum seed is best suited for bio-oil production through microwave pyrolysis as it contains low moisture content and higher cellulose. The obtained bio-oil yield is up to 48% can be found from this non-edible biomass.

Keywords: Microwave Pyrolysis; Biomass; Simulation; biofuel; Aspen plus.
1. Introduction

The global energy demand is increasing day by day. This is supported by the fact that the global primary energy consumption has grown by 2.2% in 2017. This is the fastest growth recorded since 2013. Faced with a steep decline of fossil fuel consumption such as coal, the demand for renewable energy is on the rise. The Renewable energy generation rise by 17%, thus creating the largest increment at 69 million tons of oil equivalent (mtoe) [1]. Within the alternative energy scenario, bio mass energy is quickly become the major sources for energy. This is due to the fact that biomass is abundantly available, especially in developing countries like India which have large agriculture sectors. Biomass produces renewable solid, liquid and gaseous fuels. These alternative fuels are known as bio fuels [2]. A large number of studies were conducted to find alternate fuel sources.

Bioethanol and biodiesel are showing promising results in this regard. India proposed its biofuel policy which mandates the blending of 20% biofuel to conventional petroleum fuels. Thus, biomass is considered a very effective renewable energy source it very well utilized to meet the rising energy demand in the future [3]. India is an agricultural country, and it produces tons of organic waste which can be converted into biofuels by utilizing methods like pyrolysis which reduce their environmental side effects [4]. Pyrolysis process is a form of thermochemical conversion technique of biomass to maintain a reactor in an inert atmosphere. Biomass pyrolysis results in generation of a solid waste (alternatively known as bio-char), gases and a dark brown coloured liquid yield (commonly known as bio-oil) [5]. In this study, we have chosen microwave pyrolysis instead of the conventional pyrolysis. There are several reasons behind this choice the microwave irradiation produces hotspots which influence the yield of the products in a major way. The microwave pyrolysis has higher heating rate values and the surface area of the biochar is high. Other advantages of microwave pyrolysis include non-contact heating, quick starting and stopping mechanisms, material selective heating and volumetric heating. Microwave pyrolysis also possesses a unique feature where heating occurs from the interior of the material body [6]. Microwave pyrolysis, however is a very complex process. The decomposition reaction occurring in the pyrolysis of wood material comprises a complicated sequence of reactions it varying consequently with changing heat rate effects, particle physical properties, thermodynamic properties, sample preparation methods, temperature, moisture content and residence time. By take care all of these aspects, it is essential to pursue further study to enrich and improve simulation and modelling in this particular area.

Pyrolysis process modelling, especially for microwave pyrolysis has a widespread variety of approaches with various complexity [7]. A simulation model is developed in ASPEN PLUS for a medium temperature pyrolysis. The simulation model predicts that a modelled coal burning of residual volatiles and char compounds later to pyrolysis process not only provides sufficient energy essential for endothermic reaction, drying of moisture coal apart from this it also supplies additional energy for production of power. The ASPEN PLUS simulation model can efficiently compute the yield of pyrolysis and it used optimize the operating parameters through biomass chemical property values obtained from ultimate analysis results. Though, simulation, modelling are the very best alternatives for understanding the mechanism of pyrolysis reactions, and optimizing an efficient and economic pyrolysis process model instead of performing the time consuming and expensive experimental investigation [8].

The present study aims to develop more green and renewable technology trends which will be of use to the society. In this investigation, we have compared the bio-oil yields of four types of biomass namely Acacia Nilotica (Babul seeds), rice husk, Bael shell and Calophyllum inophyllu. We have used ASPEN PLUS to simulate microwave pyrolysis and as function of input parameters, we have optimized the process.

2. Principle of microwave-assisted pyrolysis process

The microwave assisted pyrolysis technique is a recently introduced method and was initially explored Tech-En limited in UK. This method is quickly developing as one of the greatest technologies among
biomass pyrolysis processes. This is because of its effective heat transfer profile, very less residence time, opposing thermal gradients and volumetric heating, which ultimately leads to energy saving [9]. Microwave irradiation lies in the range of 0.3 and 300 GHz in terms of operating frequency and corresponding wave length of 0.01 to 1 meter on the electromagnetic spectrum, which means it lies between the radio wave region and the IR (Infra-red) regions [10]. The microwave irradiation produces microwave energy which penetrates the required material surface, and gets converted into heat energy in the particle core. This heat generated inside the material is carried towards the outside surface, which results in the generation of a temperature variation in between the surface of core in biomass and the outer layer of the particle, and volatile release in the same direction of the temperature gradient [11]. Therefore, microwave pyrolysis technology is considered a capable method to convert waste biomass into valuable green materials and high-quality biofuels.

3. Simulation and Modelling of Biomass
Advanced System for Process Engineering (ASPEN) is used to make computational modelling to simulate and optimize the process involved in microwave pyrolysis. ASPEN PLUS allows the user to develop a chain of sophisticated processes. Every block of a chain of processes can be individually tested with different parameters. In case, the block is complicated, it can be developed using FORTRAN subroutines. ASPEN PLUS is well equipped to calculate chemical, physical and biological parameters [12]. It is worth mentioning that this process of modelling can be performed by taking the biomasses as hypothetical solids in an approach quite different from the one described below. The process involves entering the various substances present in the biomass which are identified through Gas chromatography-mass spectrometry (GC-MS). This process is quite tedious and hence, was omitted in this study.

![Pyrolysis Reactor](image)

**Figure 1.** Flowsheet representing the microwave pyrolysis process.

This study uses four biomass wastes namely Acacia Nilotica, Calophyllum inophyllum seed, rice husk and Bael shell. Since, we are concerned with only the bio-oil yield of these seeds, the RYIELD reactor block is chosen. After the feed is passed through this block, the stream is passed through a condenser where the pyrolysis oil and syngas get separated. The flowsheet shown here illustrates the process.
Table 1. Biomass sample elemental analysis in terms of percentage weight.

| Biomass samples                  | Carbon | Hydrogen | Nitrogen | Oxygen | Sulphur |
|----------------------------------|--------|----------|----------|--------|---------|
| Bael Shell [13]                  | 40.67  | 6.23     | 1.34     | 51.76  | 0.235   |
| Callophylum Innophylum [14]      | 43.82  | 6.35     | 3.15     | 45.98  | 0.695   |
| Rice Husk [15]                   | 45.28  | 5.51     | 0.67     | 41.6   | 0.29    |
| Babul Seed [16]                  | 54.1   | 6.12     | 5.23     | 34.53  | 0.362   |

Table 2. Proximate analysis of biomasses in terms of percentage weight in dry basis.

| Biomass samples                  | Moisture (%) | Fixed Carbon | Volatile Matter | Ash |
|----------------------------------|--------------|--------------|-----------------|-----|
| Bael Shell [13]                  | 11.68        | 2.94         | 91.42           | 5.64|
| Callophylum Innophylum [14]      | 3.56         | 21.1         | 72.61           | 2.73|
| Rice Husk [17]                   | 1.3          | 16.8         | 69.3            | 13.9|
| Babul seed [16]                  | 12.5         | 11           | 69.1            | 7.3 |

The entire system was simulated using Peng-Robinson (PENG-ROB) property methods. All of the above biomasses were defined as unconventional solids and their proximate analysis and ultimate analysis data were inputted. The pyrolysis reactor was simulated to operate at 450-600°C. The particle size at the input of microwave reactor is taken to be 1mm.

4. Results and Discussion

Callophylum inophyllum gave the highest oil yield with 48% as its maximum yield at a temperature of around 500°C. Babul seeds (Acacia Nilotica) was capable of a maximum yield of 42% in the temperature range of 500°C. Bael shell yield maximum bio oil of 35% at 500°C temperature and Rice husk gave an oil yield around 39% in the temperature of 500°C.
There was an increase in percentage yield of syn-gas and bio-char as the temperature was increased. This was especially true for rice husk, whose bio-oil yield rapidly decreased to 25% at 600℃. This Aspen Plus model suggests that, though microwave pyrolysis is in many ways better than conventional pyrolysis it still produces lesser bio-yield and more bio-char with rise in temperature.

5. Conclusion
A computer based mathematical model was generated by utilizing ASPEN PLUS simulation software to investigate the efficiency and performance of the microwave assisted pyrolysis by selecting biomass feedstock with respect to the function of physical, chemical properties and operating conditions. Four different samples namely Acacia Nilotica, Calophyllum inophyllum seed, rice husk and Bael shell were used in the simulation separately to find out the yields of bio-oil, syn-gas and Char. The results obtained was showed that Callophylum inophyllum feedstock produced the highest output of bio-oil as 48% in the temperature range of around 500℃. and it is the best oil yielding seed amongst the four feedstocks for converting biomass into alternative fuel by using microwave pyrolysis technology.

References

[1] BP 2018 67th edition Stat. Rev. World Energy 1–56.
[2] D Vamvuka 2011 Bio-oil, solid and gaseous biofuels from biomass pyrolysis processes an overview Int. J. energy Res. 35: 835–862
[3] Mohan D, Pittman C U and Steele P H 2006 Pyrolysis of wood/biomass for bio-oil: a critical review Energy and Fuels 20 848–89
[4] Rajamohan S and Kasimani R 2018 Analytical characterization of products obtained from slow pyrolysis of calophyllum inophyllum seed cake: study on performance and emission characteristics of direct injection diesel engine fueled with bio-oil blends Environ. Sci. Pollut. Res. 25 9523–38

[5] Sharma A, Pareek V and Zhang D 2015 Biomass pyrolysis - a review of modelling, process parameters and catalytic studies Renew. Sustain. Energy Rev. 50 1081–96

[6] Huang Y F, Chiueh P Te and Lo S L 2016 A review on microwave pyrolysis of lignocellulosic biomass Sustain. Environ. Res. 26 103–9

[7] Kabir M J, Rasul M G, Ashwath N and Chowdhury A 2003 A review on green wastes pyrolysis for energy recovery recent Res. Environ. Geol. Sci. 101–7

[8] Luo Z, Wang S and Cen K 2005 A model of wood flash pyrolysis in fluidized bed reactor Renew. Energy 30 377–92

[9] De La Hoz A, Díaz-Ortiz A and Prieto P 2016 Microwave-assisted green organic synthesis RSC Green Chem. 2016–January 1–33

[10] Tripathi M, Sahu J N, Ganesan P, Monash P and Dey T K 2015 Effect of microwave frequency on dielectric properties of oil palm shell (ops) and ops char synthesized by microwave pyrolysis of ops J. Anal. Appl. Pyrolysis 112 306–12

[11] Haeldermans T, Claesen J, Maggen J, Carleer R, Yperman J, Adriaensens P, Samyn P, Vandamme D, Cuypers A, Vanreppelen K and Schreurs S 2019 Microwave assisted and conventional pyrolysis of mdf – characterization of the produced biochars J. Anal. Appl. Pyrolysis 138 218–30

[12] Puig-Arnavat M, Bruno J C and Coronas A 2010 Review and analysis of biomass gasification models Renew. Sustain. Energy Rev. 14 2841–51

[13] Bardalai M and Mahanta D K 2016 Characterisation of the pyrolysis oil derived from bael shell (aegle marmelos) Environ. Eng. Res. 21 180–7

[14] R. S and K. R 2017 Influence of temperature on yield, composition and properties of the sub-fractions derived from slow pyrolysis of calophyllum inophyllum de-oiled cake J. Anal. Appl. Pyrolysis 127 159–69

[15] Tsai W T, Lee M K and Chang Y M 2007 Fast pyrolysis of rice husk: product yields and compositions Bioresour. Technol. 98 22–8

[16] Garg R, Anand N and Kumar D 2016 Pyrolysis of babool seeds (Acacia nilotica) in a fixed bed reactor and bio-oil characterization Renew. Energy 96 167–71

[17] Pattiya A and Suttibak S 2012 Influence of a glass wool hot vapour filter on yields and properties of bio-oil derived from rapid pyrolysis of paddy residues Bioresour. Technol. 116 107–13
Acknowledgement

The authors thank the Director, National Institute of Technology, Tiruchirappalli, Tamilnadu, India for extending the facilities to carry out the research work.