INTERNATIONAL JOURNAL OF ENGINEERING TECHNOLOGY AND SCIENCES (IJETS)
ISSN: 2289-697X (Print); ISSN: 2462-1269 (Online) Vol.7 (1) June 2020

DOI: http://dx.doi.org/10.15282/ijets.7.1.2020.1010

Optimal Technological Selection for Biomass Torrefaction

Nur Hazirah Binti Mohamad Hassan*[1] *and Abdulhalim Abdulrazik*[1,2]

[1] *Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Pahang, Malaysia*

[2]*Centre for Sustainability of Ecosystem & Earth Resources, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia*

**Email: abdhalim@ump.edu.my*

Abstract- Malaysian oil palm sector plays a strategic role as the key producer for generation of renewable energy and production of biodiesel. Raw biomass has poor qualities such as high moisture content, low energy density, low bulk density and heterogeneous in nature. On the other hand, biomass could supply sustainable energy in the form of bio-power, heat and bio-fuels if the suitable pre-treatment method is applied. The biomass must be pre-treated to improve properties of biomass and make it more suitable for energy applications. One of the pre-treatment process is called torrefaction that involves heating at 300℃ under 1bar. This paper focuses on the optimal technological selection for torrefaction using Empty Fruit Bunch (EFB) as biomass source. The purpose of this study is to simulate using ASPEN Plus software of three different technologies for torrefaction using Microwave Reactor, Fluidized Bed Reactor and Rotary Drum Reactor, and to optimize the selection of those technologies based on profitability using General Algebraic Modelling System (GAMS) software. Each torrefaction technology were modelled and validated against published literatures. Criteria for optimal technological selection are production yield, capital cost and operating cost. From results indicate that the torrefaction technology using fluidized bed reactor with yield (4632.7 tons per year), operating cost (RM5,683,045.50 per year) and capital cost (RM12, 658,926.22) was selected as the optimal one for the given operating conditions

Indexed Terms- ASPEN Plus, Empty fruit bunch, Torrefaction, Simulation, Optimization.

I. INTRODUCTION

Biomass is defined as living or recently dead organisms and any by-products of those organisms, plant or animal [1]. The term is generally understood to exclude coal, oil and other fossilized remnants of organisms, as well as soils. Basically, biomass is generated in various forms such as agricultural residue, forest waste, and herb residue. Biomass resources are classified into four major types which are forestry biomass, agricultural biomass, energy crops and municipal solid waste. The energy stored in biomass can be released to produce renewable energy that can be further classified into bio-power, thermal energy and bio-fuels. The Malaysian palm oil sector plays a strategic role as the key producer of bioenergy specifically for generation of renewable electricity and in the production of biodiesel [2]. Malaysia has transformed itself from mainly an agricultural to an industrial economy, with ambitions to become a high-income nation by 2020. Biomass could supply sustainable energy in the form of bio-power and bio-fuels, if the suitable pre-treatment method is applied.

Torrefaction is a thermal pre-treatment process carried out in an inert environment which the temperature range of 200 to 300℃ to increase the energy density of lignocellulosic biomass to produce solid biofuel with similar fuel properties as coal [3]. Torrefaction is an emerging technology which enables greater co-firing rates of biomass with coal and also a method pre-process biomass and produces a solid with higher energy density, hydrophobic property, and improved grindability and has a lower oxygen-to-carbon ratio, therefore more suitable for commercial and residential combustion. The benefit of using torrefaction as a pre-treatment method before gasification is that the material is easier to mill, since the fibrous structure of the biomass has been destroyed. Another benefit from torrefaction is increased homogeneity of feedstock and a more even size distribution, which is important for steady downstream operation. High energy consumption for heating (for torrefying) is the common issue that need researches and improvements. Several types of torrefaction reactor technologies have been developed for biomass such as compact moving bed, fluidized bed, belt dryer, rotary drum, screw conveyor and microwave reactors. Most of these reactors are upgraded or adopted from either drying or pyrolysis technologies [4]. For the time being, there has limited study on technological selection for thermal-based biomass pre-treatment.

Aspen Plus is software of process modelling tool for steady-state simulation, design, performance monitoring, optimization and business planning for chemicals, specialty chemicals, petrochemicals and metallurgy industries. This software performs solids modelling. Process modelling and optimization problems are generally complex tasks, and hence computer software tools are essential for providing fast, reliable and user-friendly interface [5]. In this paper, optimization to select the best technology for biomass torrefaction with binary integrates programme by considering the product yield of torrefied, operating cost and capital cost per year was done. In order to solve the developed optimization model, the General Algebraic Modelling System (GAMS) software was used.

II. METHODOLOGY

Figure 1 shows the overall methodology in this paper. Explanations are in the following sections.

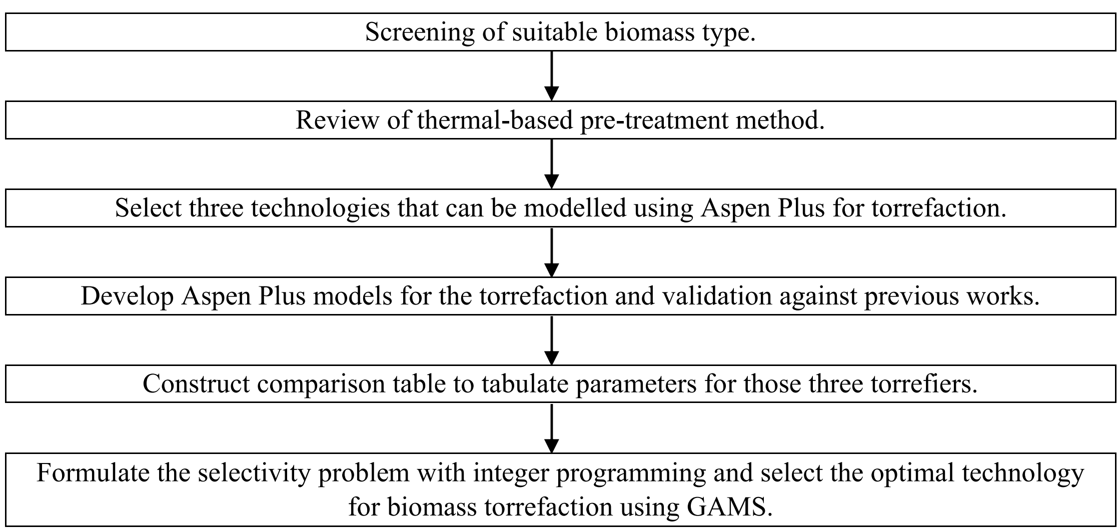

Figure 1: Overall Methodology

2.1. Screening of suitable biomass type

The suitable biomass source that undergo torrefaction will be screened by using data from proximate and ultimate analyses Both analyses are according to the methods by the American Society for Testing and Materials (ASTM). The proximate analysis includes moisture, volatile matter, ash and fixed carbon. Ultimate analysis, which more comprehensive, is dependent on quantitative analysis of various elements present such as carbon, hydrogen, sulphur, oxygen and nitrogen. The sulphur analysis content pyritic, sulphate and organic. The physical and chemical properties used showed in **Table 1**.

Table 1: Physical and Chemical Properties of EFB

Properties	Value (%wt)
Moisture	15.00
Volatile	79.82
Fixed Carbon	13.31
Ash	6.87
Carbon	43.80
Hydrogen	6.20
Oxygen	42.65
Nitrogen	0.44
Sulphur	0.44
Pyritic	0.198
Sulfate	0.044
Organic	0.198

2.2 Review of thermal-based pre-treatment method

The suitable biomass that possess high calorific value, indicated by both proximate and ultimate analyses will undergo pre-treatment process based-on torrefaction. This pre-treatment process is to improve the physical, chemical and biochemical composition of the biomass, making it perform better for energy application. The raw biomass will undergo torrefaction process known as roasting, slow and mild pyrolysis, wood cooking and high temperature drying. It will convert raw biomass into a solid that is suitable for combustion and gasification application, which has a high heating value and high energy density, hydrophobic, compactable, grinding and has a lower oxygen-to-carbon than raw biomass.

2.3 Select technologies that can be modelled using Aspen Plus for torrefaction

Based on published literatures, this step involves selection for suitable technologies for torrefaction process which can be modelled using ASPEN Plus simulator. Having said that, there are technologies that cannot be modelled in the simulator and require user defined equations. Three technologies and related ASPEN Plus simulator models were identified; microwave reactor that was modelled using RSTOIC, Fluidized Bed Reactor that was modelled using RCSTR and Rotary Drum Reactor that was modelled using RPLUG.

2.4. Develop ASPEN Plus models for torrefaction technologies and validate against previous works

Development of three simulation models for the respective three torrefaction technologies in the ASPEN Plus were started by using data from Table 1. While Peng-Robinson was selected as the thermodynamic method in the simulation, all the involved unit operations and arrows were added. Acceptance criteria for validating simulation results against published results was set at maximum 10% differences. The published result by [6] is shown by Figure 2. In this flowsheet, raw EFB is transferred to the dryer. The drying of raw EFB feed is important in order to reduce the moisture content before torrefaction stage. When the dried EFB enters the reactor, represented by RYIELD, the decomposition of the EFB takes place. Part of EFB and air enter the combustion process, represented as COMB to produce the desired flue gas which will supplement the drying process. be used in drying reactor to reduce energy usage in drying reactor based on mass balance. The separations of moisture and dried EFB, and remaining moisture and torrefied EFB are done using flashes named by Sepa1 and Sepa2.

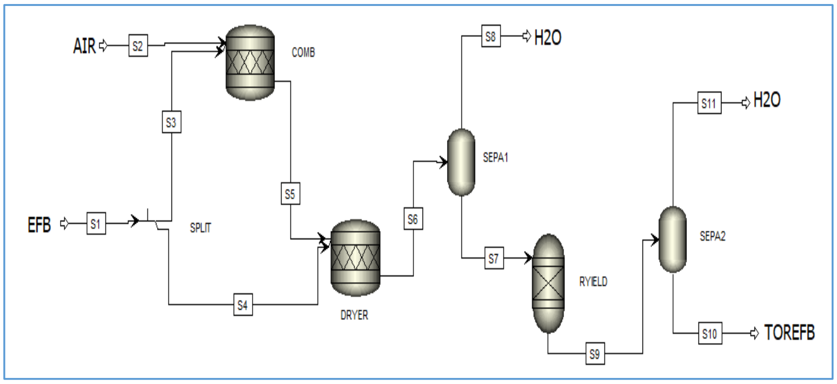

Figure 2: Process flow diagram for torrefaction process from previous work [6]

Validation against results from [6] with the accepted criteria of difference would be the base model in simulating the next three models for the respective torrefaction technologies.

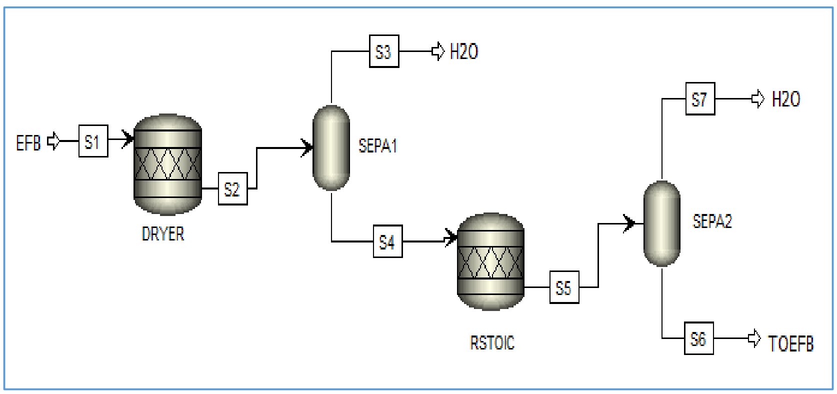

Figure 3: Process flow diagram of Microwave reactor using RSTOIC Model

Figure 3 shows simulation flowsheet for microwave system that use electricity to supply heat instead of coming from combustion based on [7]. **Figure 4** and **Figure 5** show simulation flowsheets for fluidized bed reactor and rotary drum, respectively.

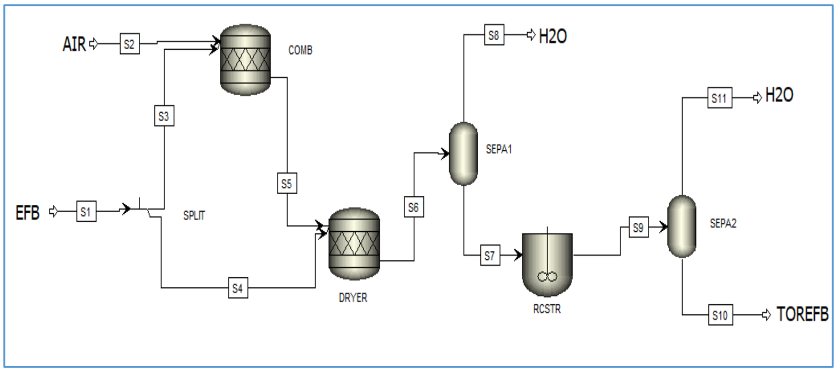

Figure 4: Process flow diagram Fluidized Bed reactor using RCSTR Model

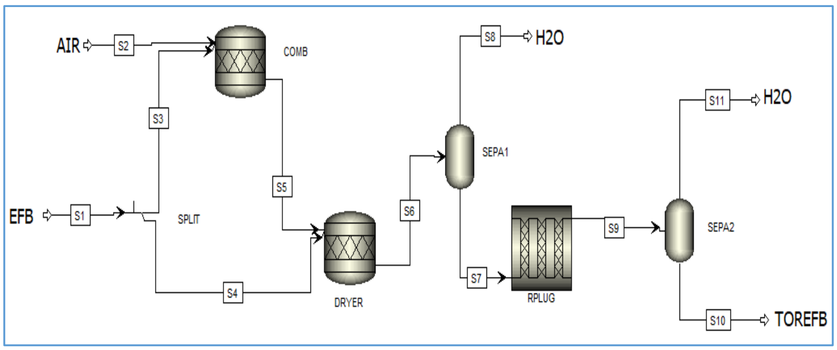

Figure 5: Process flow diagram for Rotary Drum reactor using RPLUG Model

2.5 Construct comparison table

After run the simulation in the Aspen Plus, comparison table is constructed to tabulate parameters for those three torrefiers technology with the product yield of torreffied EFB, operating cost and capital cost.

2.6 Formulate and determine the optimal technology for biomass torrefaction using GAMS

The formulation the selective problem with integer programming was based on the product yield of torefied EFB that will become a revenue, operating cost and capital cost and to select the optimal technology for biomass torrefaction using General Algebraic Modelling System (GAMS). It will be coded in GAMS for the three torrefaction technologies. **Equation 1** shows the objective function for the formulation.

Objective for maximizing function: Revenue minus costs

$$Max\ (y)= (B*C*x1 + B*D*x2 + B*E*x3) - (A*F*x1 + A*F*x2 + A*F*x3) \quad (1)$$

Three constrains were identified; i) by **Equation 2** that shows only one structural configuration would be selected, ii) constraint for the operating cost showed in **Equation 3,** iii) the constraint for capital cost showed by the **Equation 4**. In this paper, it was set that the operating cost limit was RM10,000,000.00 and the capital cost limited for RM24,000,000.00. For the selection, there were three binary variables that represent each of the simulation were defined as x1, x2, x3 which the value must be 0 or 1. Table 2 describes terms used in all equations.

c_1: x1 + x2 + x3 ≤ 1 (2)

c_2: G*x1 + H*x2 + I*x3 ≤ 10000000 (3)

c_3: J*x1 + K*x2 + L*x3 ≤ 24000000 (4)

Table 2: Descriptions of terms

Term	Category	Description
A	Parameter	EFB cost at RM7 per tonne [8].
B	Parameter	Torrefied EFB cost at RM699 per tonne [8].
C	Parameter	Product Yield from Microwave Reactor is 3,244 tonne per year.
D	Parameter	Product Yield from Fluidized Bed Reactor is 4,633 tonne per year.
E	Parameter	Product Yield from Rotary Drum Reactor is 4,633 tonne per year.
F	Parameter	Flowrate of raw EFB is 5,406 tonne per year.
x1	Binary variable	Microwave system.
x2	Binary variable	Fluidized Bed system.
x3	Binary variable	Rotary Drum system.
C_1	Constrain	One structural configuration.
C_2	Constrain	Operating cost.
C_3	Constrain	Capital cost.
G	Parameter	Operating cost for the Microwave system is RM3,980,737.99 per year.
H	Parameter	Operating cost for the Fluidized Bed system is RM5,683,045.50 per year.
I	Parameter	Operating cost for Rotary Drum system is RM4,067,630.04 per year.
J	Parameter	Capital cost for Microwave system is RM9,750,412.43 per year.
K	Parameter	Capital cost for Fluidized Bed system is RM12,658,926.22 per year.
L	Parameter	Capital cost for Rotary Drum system is RM12,801,887.77 per year.

III. RESULTS AND DISCUSSION

This part details out the results and discussion of simulating three different technologies for torrefaction in ASPEN Plus and optimization in GAMS. **Table 3** shows the comparison table to tabulate the parameters between those three torrefiers. For the production yield of torrefied EFB, the results obtained for Fluidized Bed and Rotary Drum system are similar but different for the Microwave system. The Fluidized Bed and Rotary Drum undergo combustion for the required heat of drying.

In preparing biomass for energy application, torrefaction has improved original properties of the biomass. However, this should be achieved without losing too much mass due to release of volatile product during the treatment process. This translate into production yield value which account for the revenue. Different values for the costings of the three technologies was justified by considering of the operation of the reactor, devices, other equipment and facilities. For the given operating conditions, fluidized bed system was the optimal torrefaction technology based on the maximized profitability and integer results of GAMS.

Table 3: Comparison between three torrefiers

Parameters	x1 Microwave System	x2 Fluidized Bed System	x3 Rotary Drum System
Product Yield (tonne/year)	3243.65	4632.67	4632.67
Operating Cost (RM/year)	3,980,737.99	5,683,045.50	4,067,630.04
Capital Cost (RM/year)	9,750,412.43	12,658,926.22	12,801,887.77

IV. CONCLUSION

This paper has mainly focused to simulate the three different technologies of torrefaction using Microwave reactor, Fluidized Bed reactor and Rotary Drum reactor and to optimize the selection of those technologies based on profitability using GAMS. There were three built in models in the ASPEN Plus for torrefaction to represent the reactor such as RSTOIC, RCSTR and RPLUG. It turns out that x2 (Fluidized Bed System) was the optimal EFB torrefaction technology in this case. This finding however to be improved in the future by adding refined parameters. The fluidized system may become the potential torrefaction technology for preparing EFB as suitable feedstock for energy applications.

ACKNOWLEDGEMENT

We would like to thank Universiti Malaysia Pahang for the technical assistances and supports in this work.

REFERENCES

1. Carol, W. (1987). Retrived from Environmental and Energy Study Institute: https://www.eesi.org/topics/bioenegy-biofuels-biomass/description.
2. Anandarajah, G. (2015). The Sustainability of Bioenergy in Malaysia.
3. Bergman, PCA. (2005). Torrefaction for biomass co-firing in existing coal-fired power stations. *Petten, Netherlands: Energy Cent Netherlands,* ECN-C-05-013.
4. Batidziral B., Schakel WB. (2013) Biomass torrefaction technology: techno-economic status and future prospects. Energy 62:196-214.

5. Lam, H. L., Kravanja, Z., & Varbanov, P. S. (2011). Software tools overview: Process integration, modelling and optimization for energy saving and pollution reduction. *Asia-Pacific Journal of Chemical Engineering,* 6(5). 696-712.

6. Awang, AH. (2019). Modelling and Optimization of Torrefied Pellet Fuel Production. *Pertanika J. Sci. & Technol.* 27 (4): 2139-2152.

7. Budarin, V. M. (2008). Torrefaction of reed canary greass, wheat straw and willow to enhance solid fuel qualities and combustion properties. *Elseveir, Fuel 87,* 844-856.

8. JAREP. (2017). Jengka Advance Renewable Energy Plant. Personal communication with JAREP operator during industrial attachment.