PERFORMANCE OF GASIFIER CHAMBER UNIT BY USING AGRICULTURAL WASTE

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ABSTRACT

Malaysia projected to produce 16.8 billion tonnes of biomass annually was a big challenge for waste issue. These huge numbers eventually lead the country to come up with a specific abundance of agricultural waste. Since the world is moving towards a greener earth, the act of dumping the waste in landfills or resorting it to open burning seems irresponsible and leaving the nation with no choice but nation must be proactive to rise about the issue to avoid it happens in future continuously. The process of gasification will help to address the matter, taking palm oil as feedstock which will turn into syngas is one of the alternative solutions as alternative fuel that benefit to nation. The objective of this study is to establish the properties fuel of syngas database and to determine the capability of the numerical simulation of the flow in the gasification system via computational approach in a gasifier chamber unit specifically to understand the flow inside the chamber. In addition, to facilitate the properties fuel syngas data, the analysing using the proximate analysis characters of feedstock is used. Second, CFD simulation is carried out using ANSYS Fluent software and different swirler angle such as 30º, 40º and 50º are used to observe the effect of using the swirler in chamber unit. Five agricultural waste was obtained as samples of palm kernel shell, ground coconut shell, Torrefied rubber seed, empty fruit bunch and wood chips. At 18.53, 18.00, 17.94, 18.37 and 17.39 MJ/kg respectively, all biomass samples obtained a specific high heating value test as fuel properties characteristics. From computational analysis, CFD capable to determine the flow in gasifier chamber unit. Swirler angle of 40° come out as one of the ideal angles implemented for gasifier chamber unit. It produced a fairly good result in gasification residuals and static temperature distribution.

Keywords: *Biomass, Gasification performance, Computational fluid dynamics (CFD), Flow characteristics.*

1.0 INTRODUCTION

Malaysia is blessed with an abundance of natural resources. Of which, it produces approximately 16.8 million tons of biomass annually. As reported by Palm Oil Refiners Association of Malaysia [1], Malaysia comes second after Indonesia in contributing to palm oil production in Southeast Asia at 36.7%. However, the profusion of biomass from the forestry and agricultural sector has created a profusion of processing residues or wastes that have no economic value unless they are put to energy generation use. Department of Environment in Malaysia has discouraged the open burning of biomass wastes which consequently lead to a major disposal problem [2].

Nonetheless, biomass can be beneficial with an extra edge of advantage over other resources in the context of renewable energy. This is due to its availability and mass resources with easy storage. A recent paper has shown a significant total deployment status of 17% in comparison to other technologies [3]. This means, studies of renewable energy have been positively increased in addition to statistics of around 100 relevant documents being published in Malaysia as the largest abstract and citation database of peer-reviewed literature.

Biomass is the plant material derived from the reaction between CO2 in the air, water and sunlight through photosynthesis, to produce carbohydrates that form the building blocks of biomass. The biomass resource can be considered as organic matter, in which the energy of sunlight is stored in chemical bonds. Some examples of biomass are energy crops, virgin wood, agricultural residues, food waste and industrial waste. In order to produce the syngas, the experimental test rig called gasifier unit is seem to be necessary. In general, the whole unit called gasification system.

In specific the gasification is a conversion technology that converts any carbon-containing material [4], coal for example, into synthesis gas. Gasification is a process consisting in the conversion of a solid/liquid organic compound in a gas or vapour phase and a solid phase [5], which it also called the gas phase, syngas. Carbon reacts with water in the form of steam and oxygen at relatively high pressure typically greater than 3000kPa and at temperature commonly 1100ºC to produce raw synthesis gas or syngas, a mixture composed mainly of carbon monoxide and hydrogen. There would also be by producing the syngas consisting of ash, char and carbon which would undergo the clean-up process to produce syngas capable of generating electricity or steam [4]. Table 1 shows the main chemical reactions in biomass gasification.

Table 1: Main chemical reactions in biomass gasification [6]

Type of reaction	Reaction number	Equation	ΔH_{298} kJ/mol
Pyrolysis	2.1	Biomass → Char (C) + CO + CO_2 + H_2O + H_2 + tar + + light hydrocarbons	<0
Gas-solid reactions	2.2 2.3 2.4 2.5 2.6	Char (C) + ½ $O_2 \leftrightarrow CO$ Char (C) + $O_2 \leftrightarrow CO_2$ Char (C) + $CO_2 \leftrightarrow 2CO$ Char (C) + $H_2O \leftrightarrow CO + H_2$ Char (C) + $2H_2 \leftrightarrow CH_4$	-111 -394 +172 +131 -42
Gas phase reactions	2.7 2.8	$CO + H_2O \leftrightarrow CO_2 + H_2$ $CH_4 + H_2O \leftrightarrow CO + 3H_2$	-41 +296
Comprehensive formula	2.9	Biomass + O_2 (or/and H_2O, CO_2) → → CO + CO_2 + H_2O + H_2 + CH_4 + light hydrocarbons + + HCN + NH_3 + HCl + H_2S + other sulphur gases + + tar + char + soot + ash	>0

The main parts of gasification system to resolve and produce the syngas is based on the fixed-bed reactor are the updraft and downdraft reactor. In the updraft reactor the solid moves downwards with the respect to the gasification agent and the syngas produced moves upward in counter-current, while in the downdraft reactor, both the solid and the gas moved downward in co-current flow [7]. Consequences this reactor design is important to explore the knowledge.

Therefore, the objective of this project is to establish the data properties of different feedstock by using proximate and ultimate analysis. Next, this study is to investigate the ability of numerical simulation in a gasifier chamber unit to observe the flow inside the gasifier chamber unit. Moreover, this study will determine the flow characteristics via simulation in the gasification system. To run this study, proximate data will be analysed for five sample feedstock palm kernel shell, ground coconut shell, Torrefied rubber seed, empty fruit bunch and woodchips. Fixed bed gasifier will be used in the simulation study with inlet velocity of 9 m/s. Lastly, the flow will be simulated using three different swirler angles of 30°,40° and 50°. The study is hoped to address the fundamental issue of efficiency and performance of numerical simulation of the biofuel production when combust in any chamber setup and propose a constructive approach. This study will discover the biomass characterisation through proximate analysis and flow character by observing the residuals, solid particle distribution and static temperature distribution.

Here, topic one is explained about the background of study that will cover the biomass and gasification system information, the objective of this project and scope to complete this project. In topic two is about the methodology covers in this project. It starts from flow chart information, then continues with the experimental setup for proximate analysis and last is computational fluid dynamics methodology. In this topic, the modelling of the chamber is shown; the domain and boundary condition are shared including the meshing information. In topic four is about the results and discussion obtains in this project. Last but not least is about the conclusion of this project.

2.0 METHODOLOGY

Figure 1 shows the flow chart of this study. Begin with the preparation of the samples from five types of feedstock then continue with the proximate and ultimate analysis. After that, the CFD simulation is done in this study.

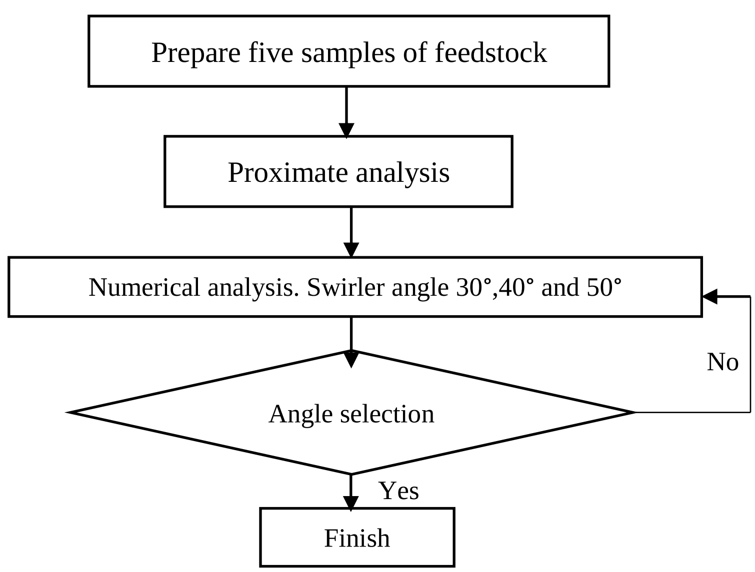


Figure 1 Flow chart of project.

2.1 Experimental Setup for Characterisation of Biomass

Three standardised tests were carried out for proximate analysis. Five biomass samples were firstly crushed into smaller bits or fine powders if possible. Materials involved were Palm Kernel Shell (PKS), Ground Coconut Shall (GCS), Torrefied Rubber Seed (TRS), Empty Fruit Bunch (EFB) and Woodchips (WC). Figure 2 shows the sieve process to make sure the sample is refined. Then, it also shows the steps of proximate analysis. The analysis comprised of moisture content, volatile content, and ash content. Each data is recorded after every heating. Figure 3 shows the test rig setup for the whole unit of gasifier including chamber unit, nozzle, turbine, and compressor.

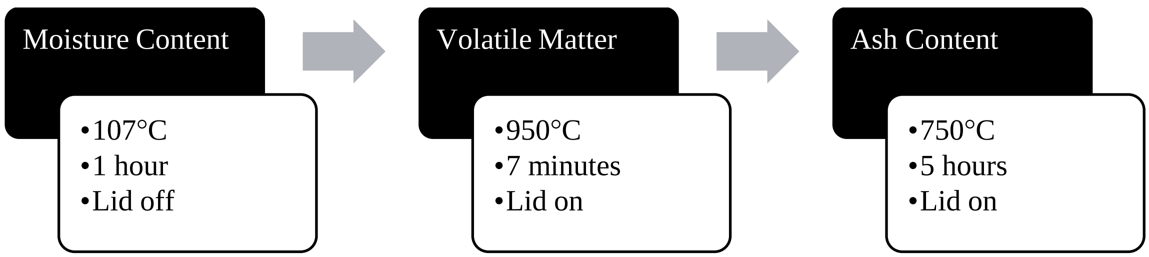


Figure 2 Proximate analysis steps.

Figure 3 Fixed bed gasifier.

2.2 Computational Fluid Dynamics Setup for Chamber Unit Modeling

In order to do the computational analysis, the model of chamber unit must ready. Modelling is according to the real model in Combustion Laboratory as shown in Figure 4. In addition, the dimensional drawing about the assembly part of the reactor is shown in Figure 5. In this project, the variations of the swirler angle are used. The angle of the swirler in the reactor will vary at 30º, 40º and 50º. Table 2 shows the swirler is different from one another. This swirler will then be assembled into a full chassis creating a gasifier reactor for simulation used. The working principle of the gasification unit happens when air goes from bottom area to the combustion area from its 90º inlet and up to outlet leading to cyclone. Biomass will be filled through the inlet letting it sits above grater during combustion as shown in Figure 4. Figure 5 shows the plan view and front view of the reactor to make sure easy to understand the setup of the chamber reactor. The swirler plate angle is purposely to reduce the temperature consistently and shown in Figure 6.

Table 2 Swirler Information

Parameter	Swirler Angle (º)		
	30º	40º	50º
Wide h, (mm)	13.6	12.3	11.2
Outer diameter D, (mm)		98	
Inner diameter d, (mm)		50	
Blade depth L, (mm)		25	

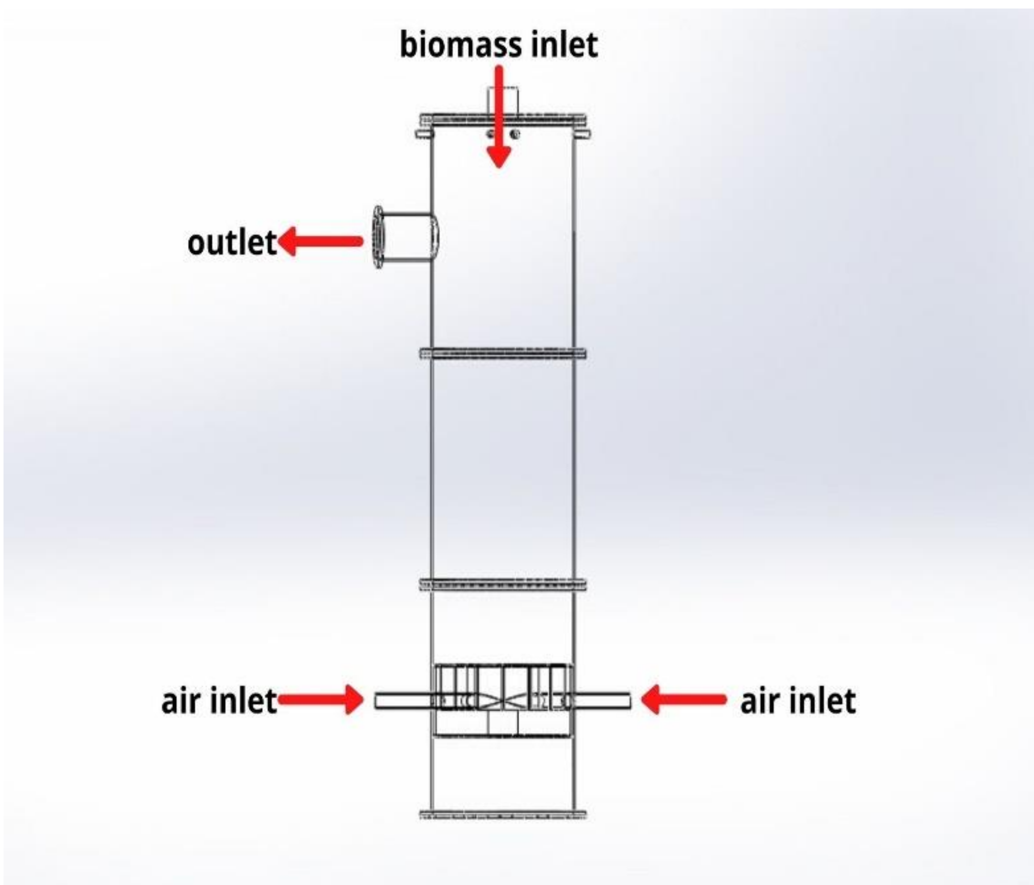


Figure 4 Cross-section of chamber unit reactor.

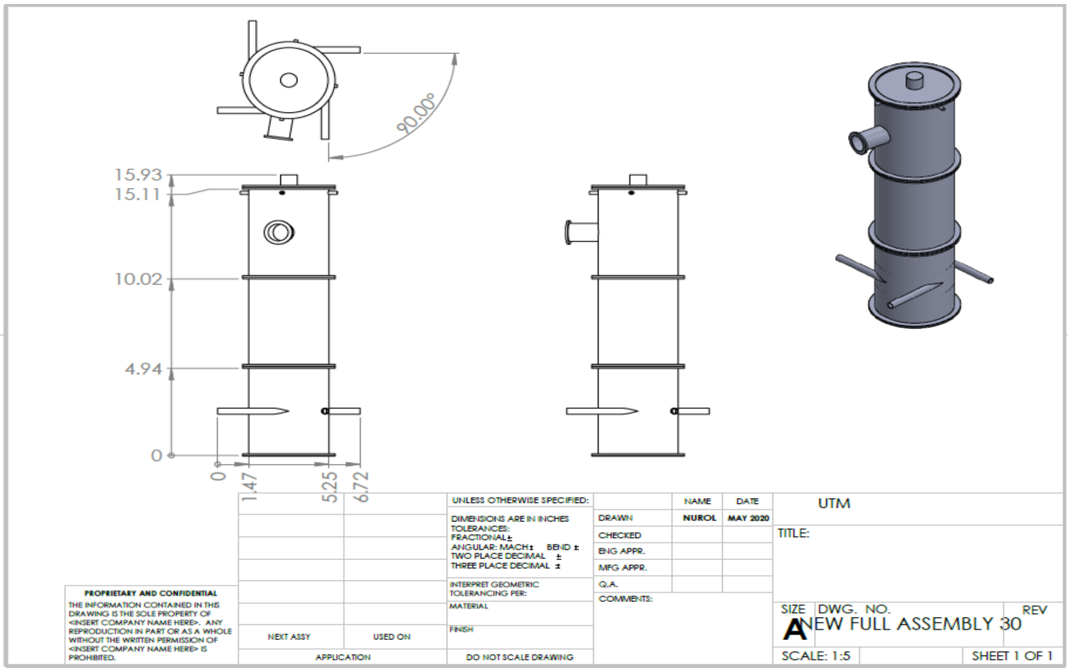
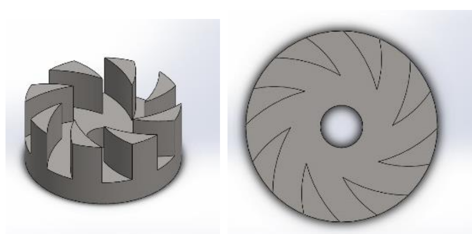


Figure 5 Assembly drawing for the reactor.



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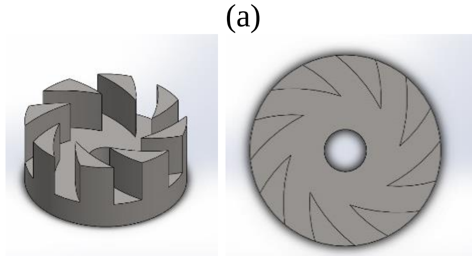

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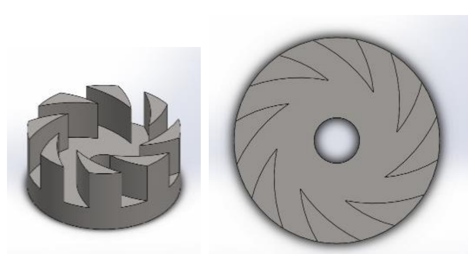


(c)

Figure 6 Swirler plate with angle (a) 30º, (b) 40º, and (c) 50º

2.3 Computational Fluid Dynamics Setup – Meshing and Boundary Condition

The solid geometry was imported to ANSYS Fluent to generate meshing. The quality of the mesh depends on the type, size, location and density of the grid. Table 3 shows the mesh value for this study to perform the convergence status for the meshing process. The simulation was run under boundary condition set-up as shown in Table 4. Boundary condition is the set to solve the numerical system. In this study, it is essential to key in the temperature parameter as different zone would have its own specific temperature. The air will flow in at high temperature of 1473K and later cooled down to 573K moving to outlets. The magnitude velocity for this project would be 9 m/s. In addition, Table 5 shows the parameter inputs to set-up the simulation for the model setting, boundary condition and solvers setting. For models setting this study uses the k-epsilon for turbulence model with intensity 10%. For boundary condition, seven boundaries are set, and for solvers, five variable conditions only pressure set as simple scheme and others variable are set as second order upwind. Figure 7 shows the meshing of the chamber unit. Combination mesh has been used for chamber unit modelling. Hexahedral meshing has been used on middle part of the reactor as it is economical for the system. On the top and bottom part of the reactor tetrahedral meshing is used as they have attachment of valves to increase meshing quality.

Table 3 Mesh Statistics

Domain	Number of nodes	Number of elements
Reactor	101333	309506

Table 4 Boundary Condition set-up

Inlet-air temperature	1473K
Outlet Temperature	573K
Magnitude Velocity	9 m/s

Table 5 Parameter inputs to set up the simulation

	Model	**Settings**	**Information**
Models Setting	Space	3D	-
	Time	Steady	-
	Viscous	Standard k-epsilon turbulence model	Turbulence intensity is 10%
	Wall Treatment	Standard Wall Functions	-
	Heat Transfer	Enabled	-
	Species Transport	Reacting	Wood-vol-air
	Discrete phase	Surface Injection	Inlet-Biomass
	Name	**Type**	**Information**
Boundary Condition	Fluid	Fluid	Air
	Inlet-air	Inlet-velocity	9 m/s
	Inlet-biomass	Inlet-velocity	9 m/s
	Drying	Wall (mixed)	Convection and Radiation
	Pyrolysis	Wall (mixed)	Convection and

			Radiation
	Oxidation	Wall (mixed)	Convection and Radiation
	Reduction	Wall (mixed)	Convection and Radiation
	Variable	**Discretisation Scheme**	**Information**
	Pressure	Simple	-
Solvers	Momentum	Second Order Upwind	-
	Turbulent Kinetic Energy	Second Order Upwind	-
	Turbulent Dissipation Rate	Second Order Upwind	-
	Energy	Second Order Upwind	-

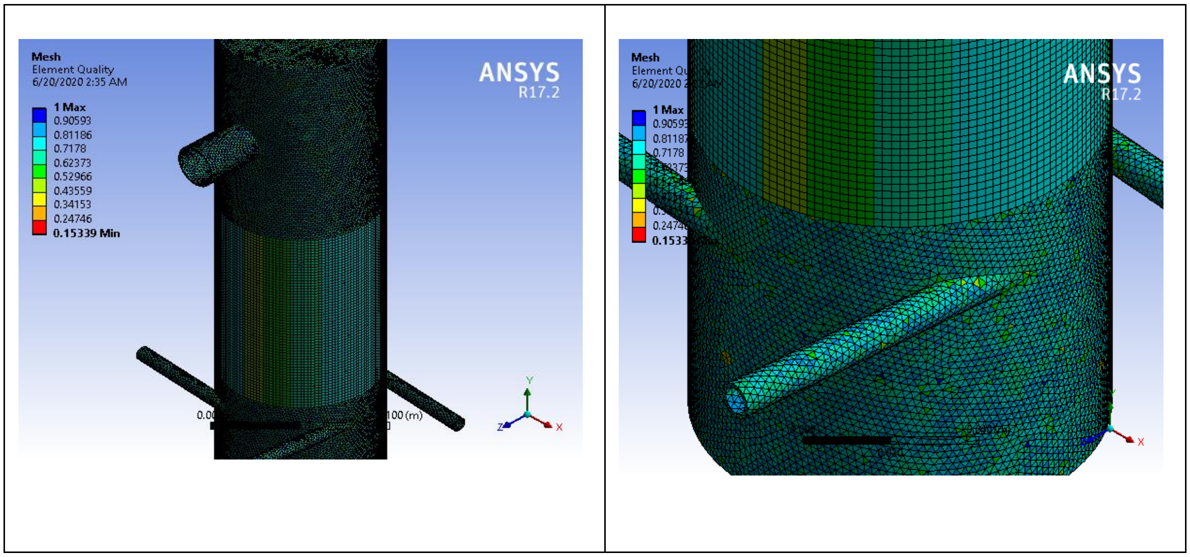


Figure 7 Meshing of Chamber unit

3.0 RESULTS AND DISCUSSION

3.1 Proximate Analysis

Data collected from proximate analysis experiment is then tabulated and presented in Table 6. Ash content for TRS is highlighted as the data went off compared to another sample. This may happen due to sampling handling during experiment. Overall, the data retrieved can be used in simulation setup as they are relevant result in past studies [8-9]. Typically, ash content would end up at less than 10% of mass fraction.

Table 6 Proximate Analysis Result

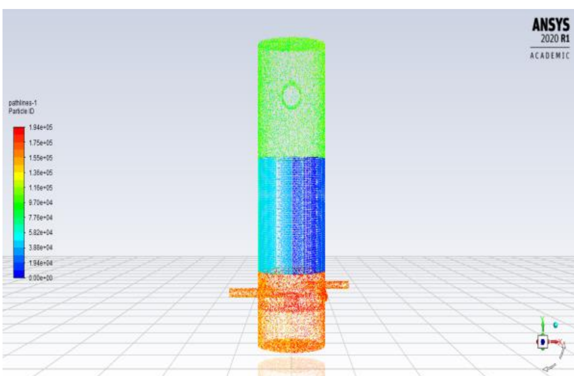
Proximate Analysis (wt%)	PKS	GCS	TRS	EFB	WC
Moisture Content	10.97	10.51	6.60	8.16	9.69
Volatile Matter	58.39	68.28	52.65	64.39	68.23
Ash Content	8.12	1.39	21.25	5.77	2.85

Fixed Carbon	22.52	19.82	19.51	21.69	19.23
HHV,MJ/kg (dry basis)	18.5329	18.0037	17.943	18.3702	17.8881

3.2 CFD Analysis

Observation made on particle path lines will enable the visualisation of trajectories that individual fluid particles follow. Path lines also act as a "recorder" for fluid element path in the flow over a certain period. At each moment in time the direction the path takes will be determined by the fluid streamlines. Figure 8 shows the different swirler angles cause particle distributions differ from one another. Results can be relatable to Discrete Phase Models (DPM) in FLUENT. This phase determines how particles are being transported from inlet valve to outlet valve. Better particles distributions will ensure better combustion. Biomass feedstock is set to have a "reflect" boundary condition type. According to Sukumaran, (2015) [11], the particle bounces the boundary off in lieu of a shift in momentum, as defined by the restitution coefficient. Moreover, through proper DPM simulation of particles combustion, it able to know the volatile development and char combustion to simulate the combustion of coal.

Figure 8 presents particle path line for reactor with swirler 30° and 50° angle show a rather similar path line. However, swirler with the 50° has a circular motion of particles and movement of solid particles during combustion where it is drag upward with the air flow because angle 50° more slope than others swirler angle [10]. However, Figure 8(b), reactor with 40° swirler presented a relatively same theory to simulation result. The immediate temperature drop once it gets to the grate condition [11].



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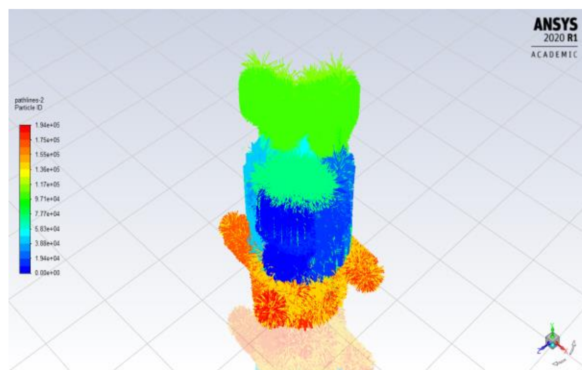

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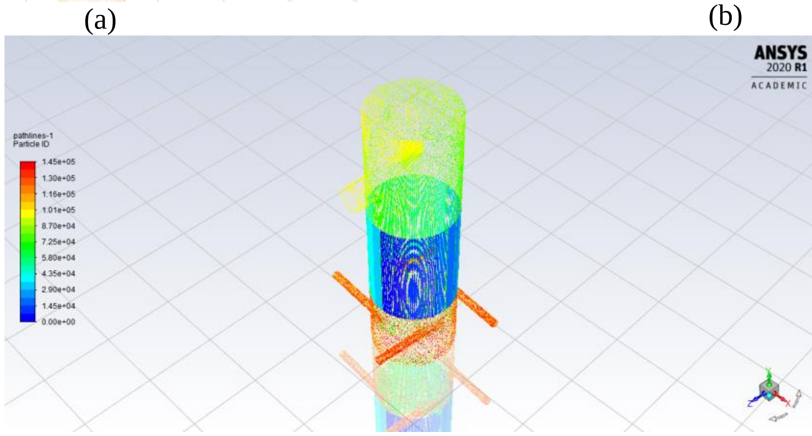

(c)

Figure 8 Solid particle path line at specific swirler angle. (a) 30°, (b) 40°, (c) 50° swirler.

Figure 9 shows the temperature distribution across the chamber unit reactor. Feeds are introduced from the top and air inlet went through from the bottom and through the grate. The lowest portion of the reactor is basically the combustion zone where devolatilisation of biomass is combusted [11]. This activity aids the heating process raising temperature to 800°C to 1000°C (1473K in ANSYS FLUENT). The upper part of the gasifier is where the hot gas pyrolyse the biomass eventually drying it. The hot gasses flowing through the bed will immediately cool down above combustion zone. The temperature of cooled gas would typically reduce to 200°C to 300°C (573K in ANSYS FLUENT). As shown in Figure 9(a) using swirler 30° and 40° the bottom area of chamber have static temperature around 573K but using 50° the bottom area of chamber little bit lower temperature, the swirler angle gives significant effect reducing the static temperature during combustion. This condition not good for combustion process. The suitable application still for swirler angle 40° because bottom area is hot then fast reduce the static temperature to the outlet area of chamber unit.

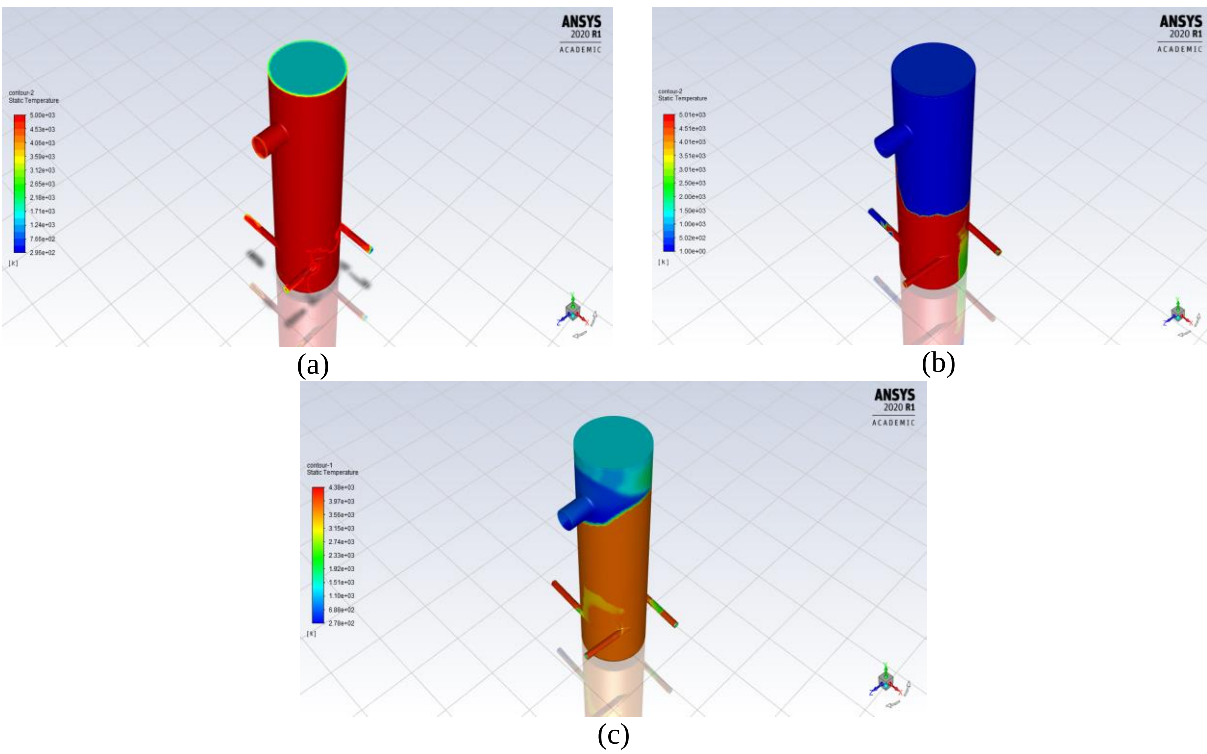

Figure 9 Static temperature distribution at specific swirler angle. (a) 30°, (b) 40°, (c) 50° swirler.

4.0 CONCLUSION

The study started off as an experimental project enabling proximate analysis studies to be carried out. Five agricultural wastes were taken as samples that are palm kernel shell, ground coconut shell, Torrefied rubber seed, empty fruit bunch and woodchips. All biomass sample gained a relevant high heating value result at 18.53, 18.00, 17.94, 18.37 and 17.39 MJ/kg respectively. Although, only one data from Torrefied rubber seed showed a slight off with ash content at 21.25% where is usually has been less than 10%. The proximate analysis successful establish the feedstock characteristics fuel for properties such as high heating value that is important to determine the capability of the feedstock to use in gasifier system.

A fundamental CFD analysis on three different angles of 30°,40° and 50° have been done to compare their effect on gasification performance. ANSYS Fluent has been an aid to the study. From simulation, two main results were attained to confirm capability of the numerical simulation to understand the flow inside the gasifier chamber unit had been discussed. Based on solid particles path lines and static temperature distribution across the chamber unit. Particle path line is seemed to be in correct motion with the use of swirler at angle 50°. While the other dispersed accordingly to each phase, only those at 50° moved along the air flow motion. Lastly, chamber unit with angle of 40° has the most accurate static temperature distribution where the air is immediately cooled to 573K after the combustion zone. In conclusion, reactor with swirler of 40° come out as an ideal swirler for gasification as satisfies the particle path line flow and static temperature distribution.

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REFERENCES

[1] Abdullah, N., & Sulaim, F. (2013). The Oil Palm Wastes in Malaysia. *Biomass Now - Sustainable Growth and Use*. doi:10.5772/55302

[2] Kavitha, B., Jothimani, P., & Rajannan, G. (2013). Empty Fruit Brunch- A Potential Organic Manure for Agriculture. *International Journal of Science, Environment and Technology*.

[3] Abdullah, W. S. W., Osman, M., Kadir, M. Z. A. A., & Verayiah, R. (2019). The potential and status of renewable energy development in Malaysia. *Energies*. https://doi.org/10.3390/en12122437

[4] Breault, R. W. (2010). Gasification processes old and new: A basic review of the major technologies. *Energies*, *3*(2), 216–240. https://doi.org/10.3390/en3020216

[5] Molino, A., Chianese, S., & Musmarra, D. (2016). Biomass gasification technology: The state of the art overview. *Journal of Energy Chemistry*, *25*(1), 10–25. https://doi.org/10.1016/j.jechem.2015.11.005

[6] Nemanova, V., Nordgreen, T., Engvall, K., & Sjöström, K. (2011). Biomass gasification in an atmospheric fluidised bed: Tar reduction with experimental iron-based granules from Höganäs AB, Sweden. *Catalysis Today*.
https://doi.org/10.1016/j.cattod.2010.12.019

[7] Härting, H. (2017). Characterization of an inclined rotating tubular fixed bed reactor. Dresden.

[8] Antonopoulos, I., Karagiannidis, A., Gkouletsos, A., & Perkoulidis, G. (2012). Modelling of a downdraft gasifier fed by agricultural residues. *Waste Management, 32*(4), 710-718. doi:10.1016/j.wasman.2011.12.015

[9] Simanungkalit, Sabar. (2013). Numerical Simulation of Gasification Process for Palm Empty Fruit Brunch Waste. *Jurnal Ketenagalistrikan dan Energi Terbarukan*. 12. 11-20.

[10] Basu, P. (2018). Biomass gasification, pyrolysis, and torrefaction. *Practical design and theory*. London, United Kingdom: Academic Press is and imprint of Elsevier.

[11] Sukumaran, R., Stöcker, M., Bhaskar, T., Pandey, A., & P., A. (2015). Recent Advances in Thermo-Chemical Conversion of Biomass. *Elsevier*.