DRYING RATE AND THERMAL PROPERTIES OF SOLID FUEL PRODUCED FROM HYDROTHERMAL AND VAPOURTHERMAL CARBONIZATION OF HIGH MOISTURE CONTENT BIOMASS MATERIAL

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DECLARATION

This work has no previously been accepted in substance for any degree and is not being concurrently in candidature for any degree.

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This thesis is the result of my own investigation, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography references are appended.

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LIST OF ABBEREVIATIONS

BG	Bagasse
LP	Lime Peel
HHV	Higher heating value
VC	Volatile organic compounds
FC	Fixed Carbon
HTC	Hydrothermal Carbonization
VTC	Vapourthermal Carbonization
HTM	Hydrothermalize Material
VTM	Vapourthermaliza Material
MY	Mass Yield
EY	Energy Yield

ABSTRAK

Peningkatan tenaga untuk biomass yang mempunyai kadar lembapan yang tinggi boleh dilakukan dengan menggunakan air (HTC) dan pengewapan (VTC) sebagai medium reaksi, dimana mengurangkan keperluan proses pengeringan seterusnya mengurangkan penggunaan tenaga. Pada masa kini, wujud beberapa analisa kadar pengeringan untuk kedua-dua HTM dan VTM. Projek ini adalah untuk menetukan pengaruh nisbah air-kepada-biomass pada kadar pengeringan didalam bentuk penggunaan tenaga dan sifat lain produk HTM dan dibandingkan dengan VTM. Selain itu, sifat HTM dan VTM diukur dan dianalisa dimana memberi kesan kepada kualiti HTM and VTM. Suhu dan tekanan adalah $220^{o}C$ dan 24 Bar kedua-duanya dan digunakan untuk proses VTM dan HTM. Pemboleh-ubah dimanipulasi untuk eksperimen ini adalah jenis biomass yang digunakan iaitu hampas tebu dan kulit limau dan kelainan nisbah air-kepada-biomass. Thermogravimetric dan Bomb Kalorimeter analisa telah digunakan untuk menetukan dan membuktikan kualiti HTM dan VTM. Keputusan menunjukkan VTM merangkumi kadar pengeringan terendah dan pengeringan tercepat dibandingkan dengan HTM dimana sampel asal adalah yang paling terendah di dalam kadar pengeringan. HTM yang mempunyai nisbah air-kepada-biomass terendah (berat tertinggi) mempunyai kadar pengeringan yang paling cepat. Tambahan lagi, kulit limau dan hampas tebu HTM dengan nisbah air-kepada-biomass 52.3:1 dan 34:1 adalah yang berkualiti dikalangan HTM untuk setiap sampel dengan HHV 18.301Mj/Kg dan 18.314 Mj/Kg. Selain itu, karbon kekal bahan asli untuk kulit limau dan hampas tebu telah dinaikkan dari 2.259%-10.538% dan 0.106%-13.428%. Walau bagaimanapun, VTM mengungguli untuk bahan yang paling berkuliti untuk kedua-dua sampel kulit limau dan hampas tebu dengan HHV 20.957 Mj/Kg dan 20.041 Mj/Kg. Kajian ini menunjukkan penetuan nisbah air-kepada-biomass yang betul adalah penting untuk menentukan kualiti HTM.

ABSTRACT

Energy improvement of high moisture content biomass material can be done by using water (in HTC) and saturated steam (VTC) as reaction medium, which reduces the necessity for drying process thus reducing energy consumption. At present, there are a few drying rate analysis on both HTM and VTM. This particular project goal is to determine the influence of water-to-biomass ratio on drying rate in term of energy consumption and other properties of torrefied product of HTM, and to compare it with VTM. Besides, the properties of torrefied product was measured and analysed which affect the quality of HTM and VTM. The temperature and pressure of 220°C and 24 Bar respectively were used for VTM and HTM and fixed for each process. The manipulated parameter of this experiment were the type of biomass used which was bagasse and lime peel and vary on water-to-biomass ratio. Thermogravimetric and bomb calorimeter analysis was done to determined and prove the quality of HTM and VTM. The result show that VTM has the lowest drying rate and rapidly dried compared to HTM while the raw material has the lowest drying rate. HTM with the lowest water-to-biomass ratio (highest weight of biomass) has the highest drying rate. Moreover, the lime Peel and bagasse HTM with ratio water-to-biomass of 52.3:1 and 34:1 are the most quality among HTM for each sample with HHV 18.301Mj/Kg and 18.314 Mj/Kg. Besides that, the fixed carbon of raw material for lime peel and bagasse sample was increase from 2.259%-10.538% and 0.106%-13.428% respectively. However, VTM was dominated for the most quality torrefied material for both lime peel and bagasse with HHV of 20.957 Mj/Kg and 20.041 Mj/Kg respectively. This study demonstrate determining the correct water-to-biomass ratio is crucial in determining quality of HTM.

1.0 INTRODUCTION

Malaysia is one of the countries that have a lot of abundant biomass resources that could be used for converting into useful energy. Utility solid biomass for electricity generation can reduce the emission of Carbon Dioxide (CO_2). Besides reducing the pollution, the power capacity could be increase. Malaysia energy demand estimated to increased up to 18kW by 2010[1]. Renewable energy such as biomass is capable provide convenient and cleaner environment. There are many process by thermochemical and biological process in converting biomass into useful energy which enhancing its properties by the biomass product. Char is a major commercial product of the thermochemical conversion process and has wide application in industries.

Hydrothermal carbonization (HTC) is a thermochemical process that converts biomass into a charcoal material called Hydro and Vapour-Thermalized material HTM and VTM respectively by applying high temperature to biomass in a suspension with water under saturated pressure for several hours [2]. HTM is the desired product in the HTC process with the mass yield of about 40 –70% [3]. Hydrothermal has two advantages of treating biomass that contain high moisture content and its ability to remove in-combustible material responsible for ash during combustion [4]. At present, upgrading high moisture content biomass material to high energy solid fuel is difficult due to its high water content which increases energy consumption for drying process.

The purpose of HTC process is to break down the rigid structure of the biomass structures into small and low molecular weight chains. The parameter that influence the destruction rate depends on the reaction time, temperature, and reaction medium. The reaction mechanism of HTC is by hydrolysis where the presence of subcritical water lowers the activation energy level of hemicellulose and cellulose, favouring rapid degradation [5].

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Exact residence time cannot be given since reaction rates remain largely unknown but typical residence times vary between 1 to 72h. Experiments with short residence time (less than an hour) have been carried out and also resulted in a significant increase of heating value of the HTM [5]. However a longer residence time leads to higher reaction severity and reduces the amount of organic losses in the wastewater. An economical way of increasing the residence time would be by recirculation of the process water [6].

The Vapourthermal carbonization (VTC) experiment was estimated to consume 2.8 times the energy per kg of biomass compared to the liquid HTC experiment by assuming reactor does not require additional power as it reaches reaction temperature, only heat as the energy input and the latent heat of vaporization of the water inside the reactor occurs at 1 atm[13].

High Heating Value of HTM and VTM increased significantly compared to the raw sample [4]. The carbon content in the biomass increases as the oxygen and hydrogen are being removed in transition of biomass to HTM [7].

For the case of straw, there are significant differences with a reproducible tendency in the carbon content between the process conditions. Carbon content follows the order HTC > VTC [8].

Based on the study of Junhong Wu et al, 2016, drying rate of the Chinese lignite, XiMeng (XM) type of coal with 60 min residence time. The higher the temperature of the treatment the lesser time required for drying the sample and inversed with the moisture content.

Energy improvement of high moisture content biomass material can be done by using water (in HTC) and saturated steam (VTC) as reaction medium, which reduces the time required for drying process thus reducing energy consumption. This particular project goal is to determine the influence of water-to-biomass ratio on drying rate in term of energy

consumption and other properties of HTM, and to compare it with VTM. Besides, the properties were measured and analysed which affect the quality of HTM and VTM.

2.0 METHODOLOGY

2.1 Raw Material

The raw materials used for this experiment were bagasse and lime peel. These material are wastes from the market and restaurant which waste are not reuse for other purposes. The amount of bagasse and lime peel (food waste) high according to the findings by Mekhilef (2011) which are 234 and 4653 kilo tonnes per year respectively. The HTC experiments were conducted within 10 days to reduce the variance caused from bio-degradation in the physical and elemental structure of the waste used in the experiment [4].

2.2 Experimental

The reactor used was specially designed and fabricated. The reactor consists of gate valve, adjustable pressure valve with a pressure gauge, perfluorelastomer O-ring for sealing, a thermocouple and a 2 kW band heater connected to an electrical box to measure and control the desired temperature. The stainless steel reactor is limited to a maximum temperature and pressure of 316ºC and 30 Bar respectively. This limitation was due to the o-ring incapable to withstand such high temperature while the thickness of wall and the cover was designed for a maximum operating pressure of 30 Bar only.

2.2.1 Hydrothermal Carbonization

The HTC was conducted using a single reactor. As shown in Figure 1, the water-to-biomass ratio was firstly determined and calculated for lime peel water-to-biomass ratio of 34(250g):1, 54(150g):1, 79(100g):1, 104(75g):1 and for bagasse the water-to-biomass ratio of 52(100g):1, 69(75g):1, 80.5(64g):1 and 90.1(57g):1.A constant 1.5 Litre of water was filled inside the reactor. Next, the weights of biomass has measured and placed inside the perforated

bucket. The perforated bucket was then placed and submerged inside the reactor. The reactor was closed and sealed by the o-ring and fastened by bolt and nut. The temperature of the water was controlled by a thermocouple and temperature controller that measured and maintained the water temperature when the temperature reached 220°C at 24 Bar, residence time of 60 minute was started. Eventually, HTM was produced and dried by electrical oven.
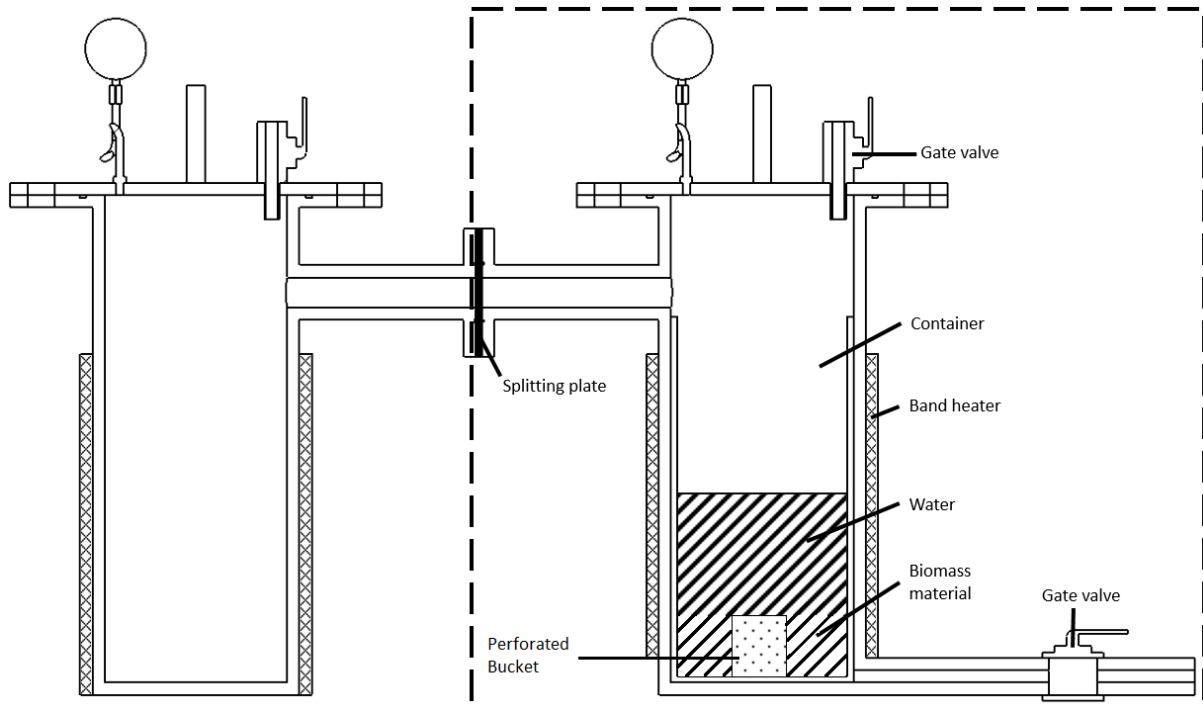
Figure 1 : Schematic of the single reactor used for HTC process

For VTC process, 4L of water and 250g of Biomass were used. Both reactors were utilized connected via flange and allowed vapour to travel to the 2nd reactor. As shown in Figure 2, on the left reactor is the main reactor where biomass was suspended 15 cm from the bottom of reactor in a perforated basket. For the right reactor acts as a boiler where an amount of water was added heated to 220°C. The steam produced was forced to fill the VTC reactor. The temperature of vapour was measured by thermocouple. The VTC heater bent was set at 150°C, to prevent any conduction of steam in the VTC reactor. The temperature and pressure was

maintained at 220ºC at 24 Bar and biomass was carbonized 60 minute of residence time. Eventually, the product was produce and dried.
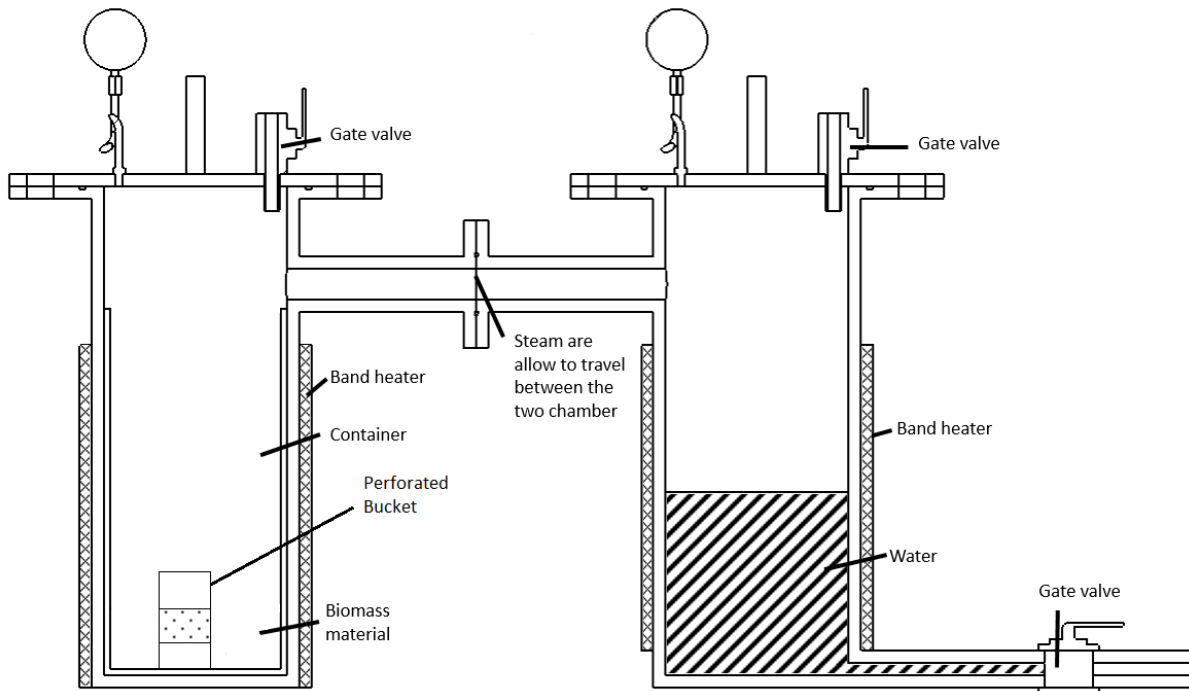
Figure 2: Schematic of dual-reactor configuration used for VTC process

2.3 Analysis and calculation

2.3.1 Drying Rate

Drying rate of produced solid fuel was determined by measuring changes in mass during drying process until constant mass was achieved (at least for 24 hours). Mass of the solid fuel was measured using Electronic Measurement Denver model TB-418 which has a precision of 0.001 gram. Drying of the solid fuel took place inside a 1.5 kW Electronic Oven Tech-Lab MFG GOV-50D model at 70ºC until mass was constant. The low drying temperature was selected to provide more resistant for bound moisture removal (Wu J, 2017), with the aim to gain more understanding on the effect of HTC and VTC on bound moisture removal. For comparison, raw material were also dried at the same condition as HTM and VTM.

2.3.2 Moisture Content

In order to determine the amount of moisture for the selected wastes. The moisture measurement was based on ASTM-E871-82 (2013). First, a plate was cleaned and dried for 30 minute at 103^0C temperature by the oven dehydrated the moisture on the plate. The weight of the plate was measured and recorded. Approximately 50 gram of the sample was measured on the weighing scale and recorded (M_R) and placed on the plate (M_i). Next, the sample was dried in the electrical oven at 103^0C for first 16 hour and the weight was measured and recorded (M_{16H}) and dry again for another 2 hours in the oven. After 2 hours the weight of the sample was weighted and recorded (M_{2H}^0). The weight of 16 hours and 2 hours of drying (M_f) is calculated by Equation 1 to verify if the weight was reduced less than 2% and required further drying of 2 hours. Eventually Moisture content was able to be measured by Equation 2.

$$\frac{M_{16H} - M_{2H}^0}{M_{16H}} \; x \; 100\% < 0.02\% \dots Eqn \; 1 \quad [\% \; of \; moisture \;] = \frac{M_i - M_f}{M_R} \; x \; 100\% \dots Eqn \; 2$$

2.3.3 Proximate Analysis

HTM should have different properties compared to its raw material. After the carbonization process of biomass the fixed carbon, volatile matter and ash content was measured by Thermogravimetric Analysis (TGA). The analysis was set up by following the Standard Operation Procedure (SOP) of the Pelkin Elmer,Thermogravimetric Analyser (TGA) Pyris 1. In the TGA analysis program, initially gas was switched to Nitrogen at 20.0 ml/min and the sample was heated from 40°C to 110°C at 20°C/min to measure the moisture content and hold for 10.0 min at 110.00°C. The sample was the heated from 110.00°C to 900.00°C at 20°C/min to measure the Volatile Matter. Finally, the gas was immediately switched to oxygen and held for 20 min at 900°C to measure the fixed carbon and ash content of the sample.

2.3.4 Bomb Calorimeter

The HHV of HTM and VTM was measured to determine suitability as a fuel using a bomb calorimeter of Nenken Model 1013-B. The samples were crushed to ensure its homogeneity. HHV of the sample was calculated using Equation 3.0 where $(M_w)_{cal}$, the equivalent water mass of the calorimeter is 604g; M_w, mass of water in the inner cylinder is 2100g; c_{water}, specific heat capacity of water is 4.19J/g; $T_{maximum}$ is the maximum temperature reached; T_o is the initial temperature; $M_{rice\ paper}$ is the mass of rice paper; $E_{rice\ paper}$, energy content of rice paper which is 17×10^3J/g; $L_{fuse\ wire}$ is the length of burned fuse wire; $E_{fuse\ wire}$, energy content of the fuse wire is 9.64J/cm; and $M_{material}$ is the mass of the material.

$$HHV = \frac{((Mw)cal + Mw) \times Cw \times (Tmax - To) - [(Mrice.paper \times Erice.paper) + (L \times E)fuse\ wire]}{Mmaterial} \ldots eqn\ 3.0$$

2.3.5 Mass yields and conversion efficiency

There are two important characteristics for HTC and VTC process that can be obtained based on the weight reduction and energy increment. The mass yields and conversion efficiency ($\eta_{conversions}$)of the carbonize materials can be calculated based on the Equation (4) and (5) [9].

$$Mass\ Yield(\%) = \frac{Mass_{HTM/VTM}}{Mass_{raw\ biomass}} x100\% \ldots Eqn\ 4$$

$$\eta_{conversion} = \frac{Mass\ Yield(\%)}{100} \ x \ \frac{HHV_{HTM/VTM}}{HHV_{raw\ biomass}} x100\% \ldots Eqn\ 5$$

2.3.6 Energy consumption for drying teatment

Energy consumption was measured by using Equations 6 and 7. In order to analyse the economic feasibility of the HTM and VTM drying cost is calculate based on Equation 6 and 7. Where the power rating for the Electronic Oven Tech-Lab MFG GOV-50D model was 1.5kW. Based on study of Yeoh Keat Hor et al, 2016. The wattmeter was used to determine the energy consumption. The result was insignificant value of the wattmeter and the calculation. Thus

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Equation 6 was used instead of using wattmeter for energy consumption measurement to save time and cost. An economic evaluation was made to calculate drying costs involved in after treatment process. Based on tariff rates provided by Tenaga Nasional Berhad (TNB) the tariff rate of 0.218 RM/unit was taken into account and the drying cost was calculated by Equation 7.

$$energy\ consumption\ (unit/kWh) = period\ of\ operation\ (hours) \times power\ rating\ (kW)\qquad \text{Eqn 6}$$

$$cost\ of\ energy\ consumption\ \left(\frac{RM}{kWh}\right) = energy\ consumption\ \left(\frac{unit}{kWh}\right) \times tariff\ rate\ \left(\frac{RM}{unit}\right)\qquad \text{Eqn 7}$$

3.0 RESULT AND DISCUSSION

Lime peel and bagasse are high moisture biomass. The percentage of moisture for both materials are 84.789% and 70.43% respectively. Both material are incapable to be treated in most of the char production process such as pyrolysis. Hydrothermal carbonization process has been proven for it reliable on processing wet biomass material. By referring Figure 3, all of the HTM HHV increase compared with the raw materials of the sample. For both lime peel and bagasse, the HHV decrease when the ratio of water to biomass increase. This reaction is due to the rapid degradation of the molecular chain by the presence of water as stated earlier.

The ratio of water to biomass is required to determine the quality of HTC char. The water to biomass ratio for both sample are not the heed to be determined for each Biomass for maximum char production.

By referring Figure 3, the fixed carbon content for both sample follow the trend of the HHV. For bagasse HTM sample, at water-to-biomass ratio 69:1 has maximum HHV (18.104 Mj\Kg) and fixed carbon (13.068%).For lime peel sample, the maximum HHV (18.431Mj/Kg) and fixed carbon (21.114%) occur at water-to-biomass ratio 52:1. The result indicate that the determination water-to-biomass is ratio crucial in determining a quality HTM. The higher

amount of sample use to water the better the char produce with a higher amount of FC and HHV.

Both VTM sample are observed to be highest in increasing the HHV and FC of the biomass compared to HTM. There is advantage and disadvantage of the VTM even though the VTM product has higher in HHV and FC and it will be discussed in the next paragraph.
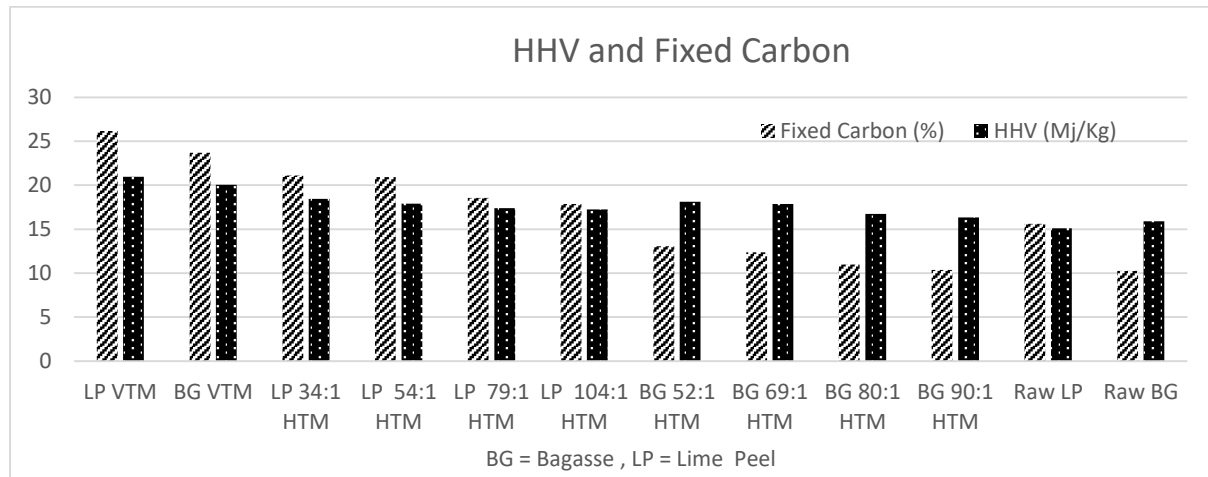

Figure 3 : HHV and Fixed Carbon

HTM and VTM sample required after treatment process which is drying before it can be fully utilized as fuel. The rate of drying for all sample was compared in Figure 4. There are significant differences for both raw and HTC product on drying rate (g% hour^{-1}). HTM and VTM are rapidly dried compared to raw bagasse and lime peel sample. The higher the weight of the HTM (lowest water-to-biomass ratio) the longer time it took to be dried due to higher of moisture content absorb by the sample.

For lime peel sample, the drying rate for HTM with ratio 104:1(75g HTM) is the highest compared to the others. Moreover, HTM LP with ratio 34:1(250g HTM) has the longest period for drying. This drying analysis is conveniently analyse on Figure 5 where the drying rate of the lime peel HTM 104:1 ratio is 23% hour^{-1} whereas the lime peel HTM 34:1 ratio is 8% hour^{-1}. As expected, the drying rate of the raw sample is the lowest compared to the HTM with 7%

hour $^{-1}$ of drying rate. Lower drying rate consumes more time for drying the sample. In addition, the raw lime peel takes more time before it can reach equilibrium rate of drying followed by HTC with water-to-biomass ratio of 34:1, 54:1, 79:1 and 104:1 respectively. Which infer that the highest weight of biomass use the more moisture it absorb in the HTC process thus required more time to be dried.

.   Similar trend was observed for bagasse where the highest weight of the HTM (90:1,57g HTM) took a longer time it take to be dry but the raw bagasse has the lowest drying rate and longest time for drying followed by HTC water-to-biomass ratio of 52:1, 69:1, 80.5:1 and 90:1 respectively. HTC was successfully remove the moisture as well as the bound water trapped in the lignite and has an advantage and feasible as a fuel [14]. HTC results in efficient moisture removal compared to raw material. Lime peel VTM was observed to be among the fastest to dry compared to HTM and Raw sample. Referring Figure 5, the initial drying rate for VTM LP is not as high as the HTM LP with ratio 104:1 but still dried more rapidly than HTM LP 104:1.
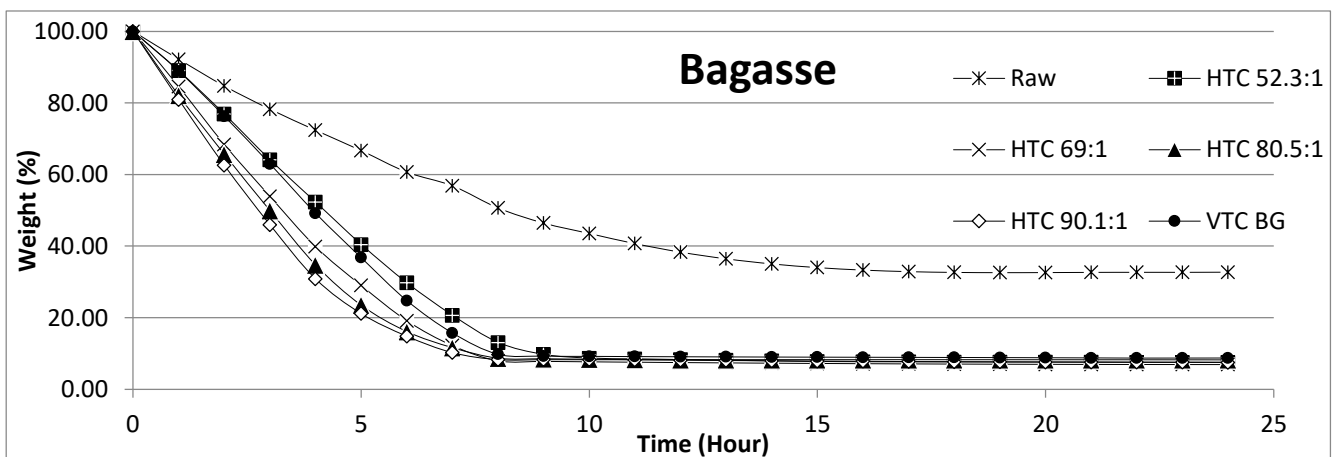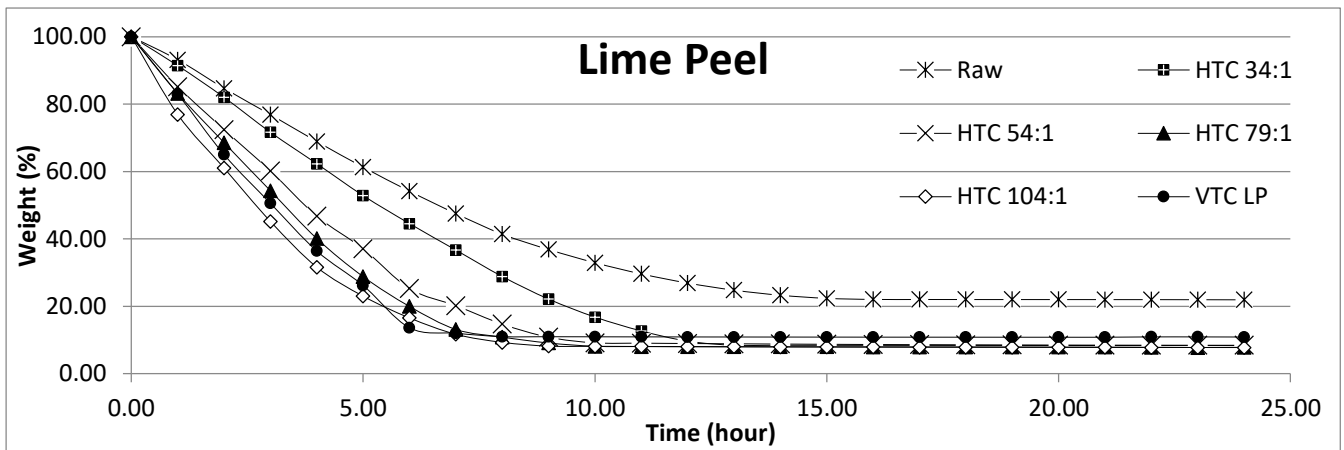
Figure 4 : Drying profile of sample
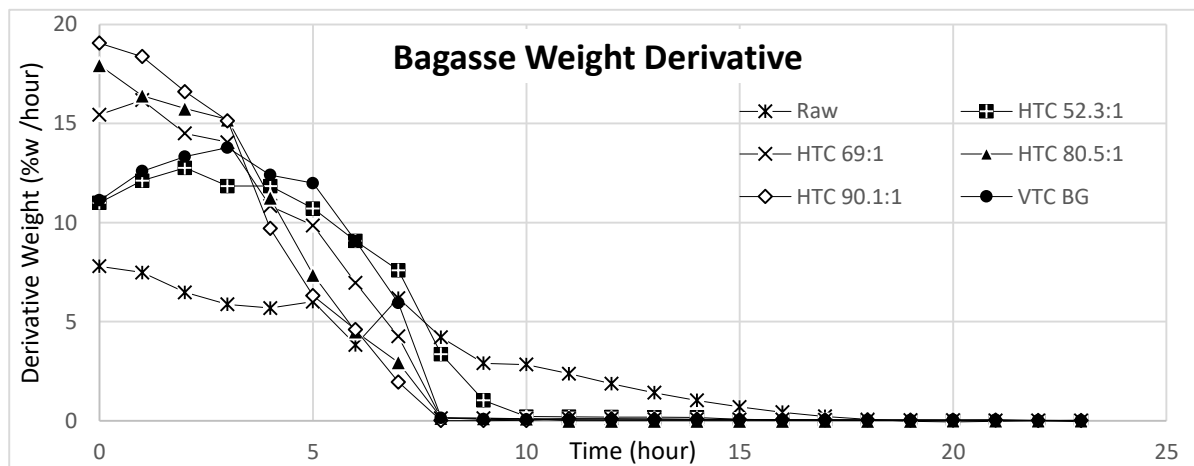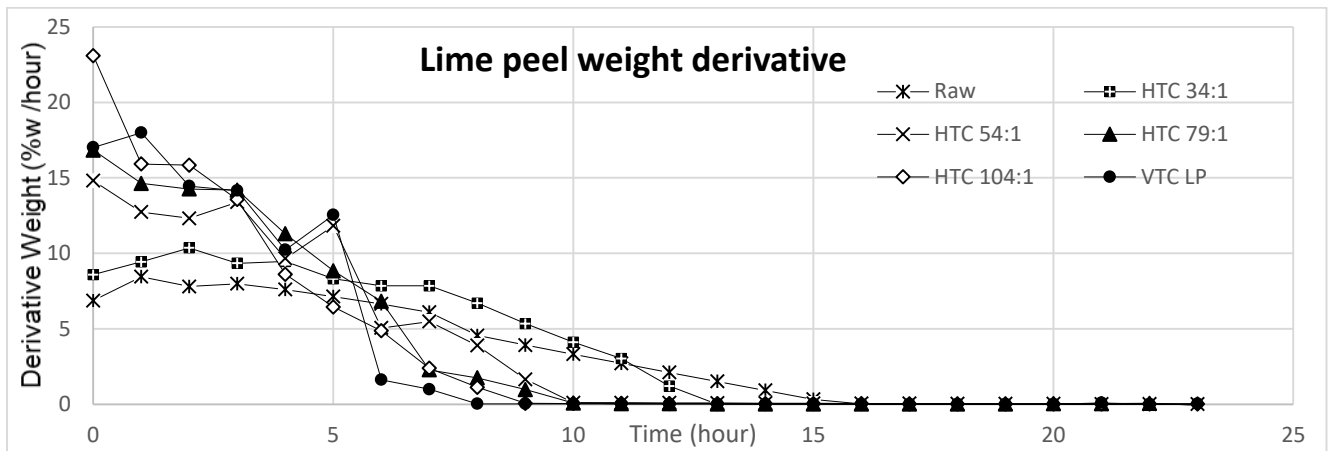
Figure 5 : Derivative weight profile

Bagasse VTM drying period observed to be slower compared to other 3 HTM BG. In term of drying rate VTM BG started the same as HTM BG 52:1 but eventually VTM BG observed to be completely dried before HTM BG 52:1. Altogether, the mass of VTM used twice and more than HTM use for both sample. Even though as observed in bagasse that VTM BG is dried slower compared to HTM BG but with comparison of weight of Biomass used we

can infer that VTM is effectively in after-treatment process compared to HTM and HTC process are proved to be effective in drying compared to the raw sample.

Drying costs for HTM and VTM are calculated by using Equation 7 and 8. Generally the less time consume for the treatment of HTM and VTM the lesser cost that will be incurred. The raw sample of lime peel and bagasse will be the highest cost for it to be completely dried by the Electrical Oven which will cost RM 4.91KW/h and RM3.92/KWh respectively due to the low of drying rate compared to HTM and VTM.

For HTM, the lowest cost contain the lowest amount of weight of biomass and cost about RM2.62/KWh and RM2.94/KWh for 34:1 lime peel and 90:1 bagasse HTM respectively. As discuss earlier, VTM bagasse dried slower than HTM BG 69:1, 80:1, and 90:1 resulting in higher energy consume consequences in higher cost. Besides that, VTM LP are the cheaper among LP which will cost RM2.62 only with heavier weight are used compare to HTM. The Raw material for both sample are not economically dried. Therefore, HTC and VTC are proved for its capability in cost reduction on drying treatment

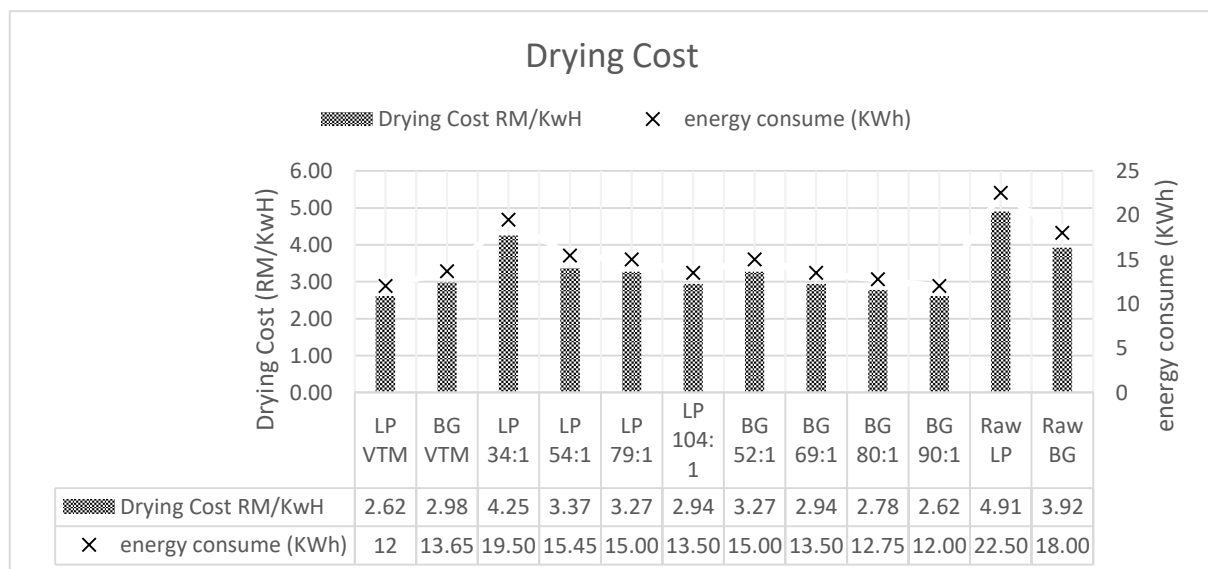|	LP VTM	BG VTM	LP 34:1	LP 54:1	LP 79:1	LP 104:1	BG 52:1	BG 69:1	BG 80:1	BG 90:1	Raw LP	Raw BG
Drying Cost RM/KwH	2.62	2.98	4.25	3.37	3.27	2.94	3.27	2.94	2.78	2.62	4.91	3.92
energy consume (KWh)	12	13.65	19.50	15.45	15.00	13.50	15.00	13.50	12.75	12.00	22.50	18.00

Figure 6 : After treatment process cost

As shown by Figure 7, the volatile matter is decreasing as the percentage of FC increase. Significant increase amount of FC are observe for both VTM LP and BG sample. The lower the volatile matter indicate that the coal are harder to be ignite and shorter flame length. As discussed, high content of Fixed Carbon are directly be related to high HHV. The ash content shown insignificant of value for all sample.
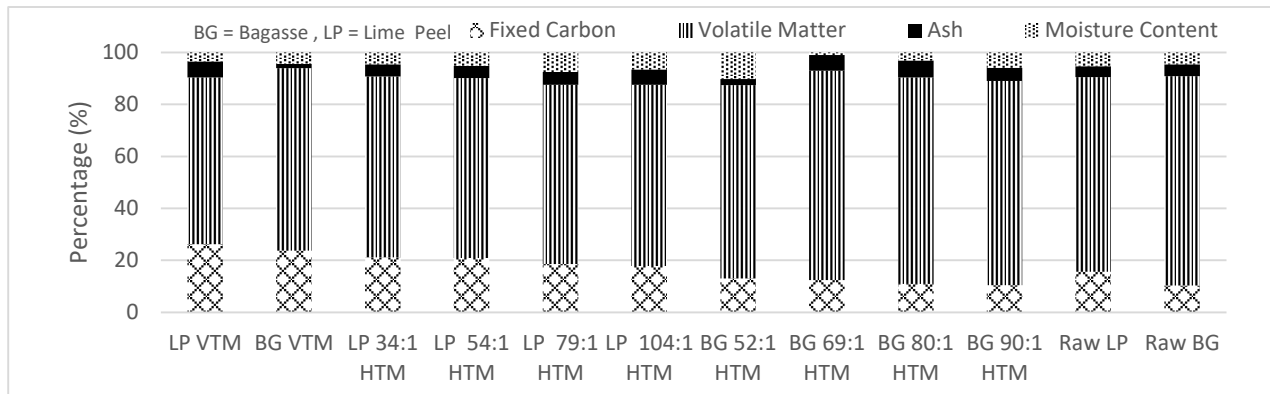
Figure 7: Proximate analysis of the sample

Differential Thermal Gravimetric (DTG) profiles on Figure 8 show the combustion process of the HTM, VTM and raw Sample. For both samples the raw material DTG is observed to fluctuate more than HTM and VTM. The initial peak range at temperature 0-100°C observed is the removal of moisture content in the sample and there is no significant value on this initial peak. The VTM and HTM DTG profile are way smoother than raw material sample. The slight bum observed on the DTG graph shows that the raw sample is less homogenous due to higher rate of reaction.

Generally the raw material contain of high VM was consequences of ignition at lower temperature. As shown in Figure 7, both raw sample are ignite at lower temperature of VM than HTM and VTM due to high reactivity of Raw Sample, resulting in narrow temperature range compared with the HTM and VTM.

Besides that, VTM show more stable in weight reduction compared than HTM. The secondary peak as observed on the graph shows that the sample is ongoing thermal decomposition such as VM losses, combustion of Hydrocarbon and FC. The HTC product

combust at high temperature and wider range of temperature compared to raw sample hence the HTC product for LP and BG sample are successfully converted to be charcoal like characteristic. Where the highest temperature for LP sample is the VTM LP.

As discuss, the VTM LP is the highest amount of FC and low in rate of reaction are the reason of longer time for the combustion of a material and combust at high temperature with a high temperature combustion zone. Next, BG 80:1 is observed to be the highest in DTG profile but shorter in temperature range compared with VTM BG. The wider temperature range of VTM is because the FC content in VTM LP is measured to be the highest with low amount of VM. For the other material such as Eucalyptus leaves and Coconut fibre based on literature [17] the trend of DTG profile are observed similar with this
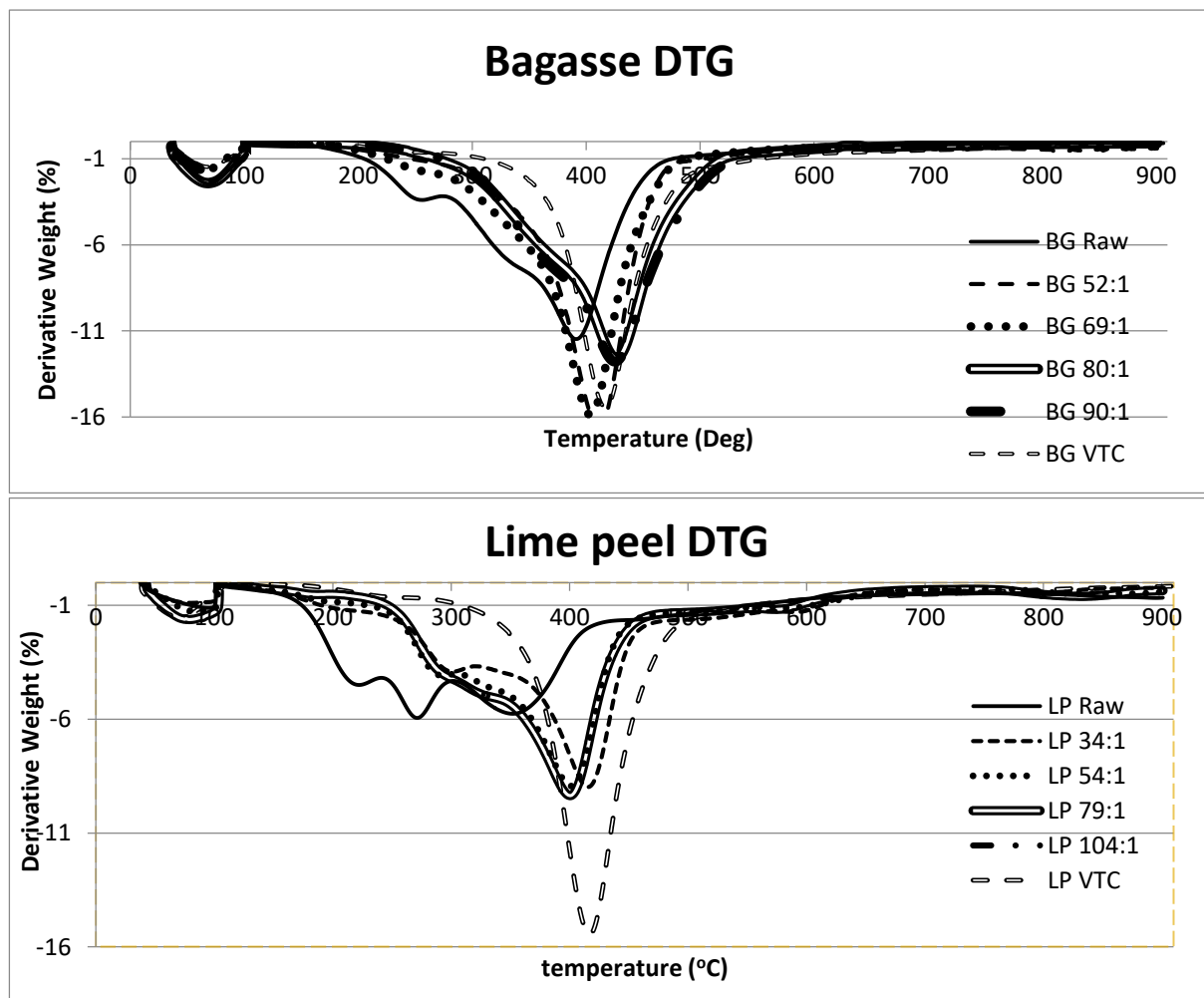

Figure 8 : Derivative Temperature Graph (DTG)

experiment. Thus we can infer that HTC process is capable to produce coal-like material with various type of biomass with advantage of increased fuel quality from the raw biomass without requiring major redesign on power plant and resulting in cost reduction.

The conversion efficiency also known as energy yield is to show how much of HTM and VTM energy increase compared to raw material. The calculation is based on Funke et al, 2013. Based on previous studies, the value of VTM process reach maximum at 70% of conversion efficiency even though the carbon content of VTM is lower compared to HTM for the case of straw.

Histogram Chart on Figure 8 show that conversion efficiency of all sample. For the case of Lime Peel HTM, the highest conversion efficiency is at biomass-to-water ratio of 54:1. Insignificant increasing HHV of HTM are resulting the mass yield to be a bigger influence in the conversion efficiency where as shown on Figure 8 the higher HHV is held by 34:1 but with lower mass yield compared to the ratio of 54:1. The trend is similar for the Bagasse HTM, where the highest peak of conversion efficiency is held by 80:1 water-to-biomass ratio.

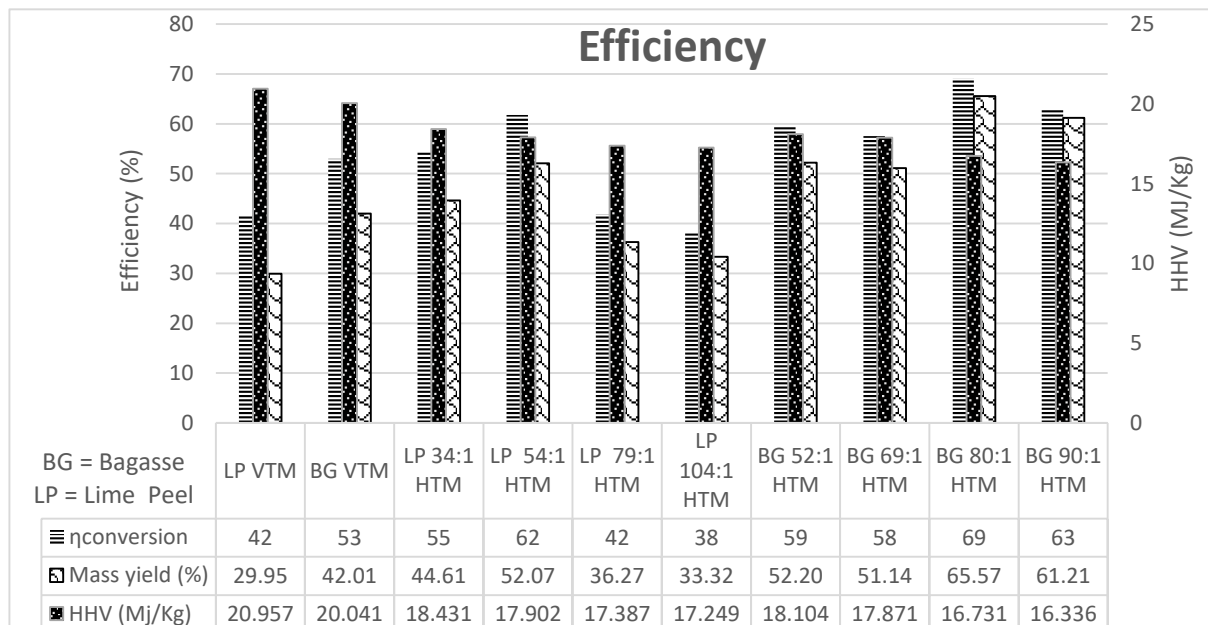| BG = Bagasse LP = Lime Peel	LP VTM	BG VTM	LP 34:1 HTM	LP 54:1 HTM	LP 79:1 HTM	LP 104:1 HTM	BG 52:1 HTM	BG 69:1 HTM	BG 80:1 HTM	BG 90:1 HTM
ηconversion	42	53	55	62	42	38	59	58	69	63
Mass yield (%)	29.95	42.01	44.61	52.07	36.27	33.32	52.20	51.14	65.57	61.21
HHV (Mj/Kg)	20.957	20.041	18.431	17.902	17.387	17.249	18.104	17.871	16.731	16.336

Figure 9 : Conversion Efficiency and its influence

VTM BG conversion efficiency is the lowest due to low mass yield of the sample even though the HHV achieve is the highest for the BG sample but it is not sufficient to increase its

conversion efficiency. This trend is similar for the case of Lime Peel where the conversion efficiency is lower than HTM LP 54:1 and 34:1 due to low HHV and low of mass yield. This result is completely against the result of recent study where the conversion efficiency of VTM is greater than HTM for the case of Bagasse but for Lime Peel sample, VTM LP is more efficient than some of HTM LP. Moreover, the rate of reaction of HTM is higher than VTM resulting in low efficiency of the VTM [24].

4.0 CONCLUSION

Water-to-biomass ratio is a crucial parameter in determining the quality of HTC and VTC product. VTM has the highest in drying rate for both samples with the consequences in cost reduction after treatment process compared to raw and HTM. The VTM are the most coal combustion characteristic with a wider temperature range in combustion combust at and combust at higher centre of combustion zone due to high FC and HHV of the VTM in DTG profile. The highest conversion efficient for HTM are 54:1 with 62% and 80:1 with 69% for LP and BG sample respectively. The VTM product is proved to be inefficient in energy conversion even though containing high FC and HHV. Thus we can infer that VTM has the advantage of drying cost, combustion characteristic, HHV and FC content compared to HTM.

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APPENDICES

Biomass material	Configuration	FC (%)	VM(%)	ASH(%)
Lime Peel	LP 34:1	21.114	69.665	4.654
	LP 54:1	20.915	69.227	4.654
	LP 79:1	18.568	69.028	4.924
	LP 104:1	17.875	69.749	5.843
	Raw LP	15.616	74.958	4.187
	LP VTM	26.154	64.276	6.125
Sugarcane Bagasse	BG 52:1	12.356	80.646	6.064
	BG 69:1	13.068	74.404	2.278
	BG 80:1	10.974	79.401	6.564
	BG 90:1	10.366	78.675	5.081
	Raw BG	10.26	80.665	4.561
	BG VTM	23.688	70.324	1.624

Table 1 : Proximate analysis

Biomass material	Configuration	Initial mass of biomass (g)	Mass of dried biomass (g)	Mass of dried HTM (g)	Mass yield (%)
Sugarcane bagasse	BG 52:1	100	30	15.659	52.20
	BG 69:1	75	22.5	11.507	51.14
	BG 80:1	64	19.2	12.589	65.57
	BG 90:1	57	17.1	10.467	61.21
	Raw BG				
	BG VTM	150	45	18.905	42.01
Lime Peel	LP 34:1	250	50	22.306	44.61
	LP 54:1	150	30	15.621	52.07
	LP 79:1	100	20	7.254	36.27
	LP 104:1	75	15	4.998	33.32
	Raw LP				
	LP VTM	250	50	14.977	29.95

Table 2 : Lime Peel and Bagasse configuration

		Bagasse						Lime Peel			
Time (hour)	Raw	HTC 34:1	HTC 54:1	HTC 79:1	HTC 104:1	Time (hour)	Raw	HTC 52.3:1	HTC 69:1	HTC 80.5:1	HTC 90.1:1
0	100.00	100.00	100.00	100.00	100.00	0	100.00	100.00	100.00	100.00	100.00
1	93.13	91.41	85.18	83.16	76.91	1	92.21	89.00	84.56	82.06	80.94
2	84.68	81.97	72.45	68.53	60.99	2	84.72	76.89	68.38	65.66	62.57
3	76.88	71.62	60.13	54.26	45.15	3	78.25	64.13	53.89	49.91	45.97
4	68.90	62.28	46.74	40.08	31.58	4	72.38	52.28	39.83	34.71	30.83
5	61.29	52.82	37.08	28.79	22.98	5	66.69	40.44	29.00	23.46	21.13
6	54.16	44.51	25.25	19.94	16.53	6	60.68	29.73	19.15	16.09	14.82
7	47.51	36.66	20.20	13.13	11.67	7	56.85	20.66	12.19	11.59	10.23
8	41.42	28.82	14.73	10.86	9.29	8	50.66	13.07	7.93	8.64	8.27
9	36.86	22.12	10.84	9.11	8.17	9	46.45	9.71	7.80	8.49	8.26
10	32.94	16.78	9.19	8.14	8.11	10	43.55	8.68	7.68	8.36	8.26
11	29.63	12.67	9.08	8.05	8.06	11	40.71	8.47	7.57	8.25	8.24
12	26.92	9.64	8.98	8.02	8.01	12	38.34	8.27	7.47	8.25	8.13
13	24.81	8.43	8.90	8.00	7.97	13	36.47	8.08	7.38	8.24	8.03
14	23.30	8.42	8.82	7.98	7.94	14	35.05	7.90	7.30	8.24	7.95
15	22.39	8.41	8.75	7.97	7.90	15	34.03	7.73	7.22	8.24	7.87
16	22.07	8.40	8.69	7.96	7.88	16	33.33	7.66	7.16	8.23	7.81
17	22.05	8.39	8.64	7.95	7.85	17	32.90	7.63	7.10	8.23	7.75
18	22.04	8.38	8.59	7.93	7.83	18	32.68	7.61	7.05	8.23	7.70
19	22.03	8.37	8.55	7.92	7.81	19	32.61	7.59	7.01	8.22	7.66
20	22.02	8.36	8.52	7.90	7.80	20	32.64	7.57	6.98	8.22	7.62
21	22.02	8.35	8.50	7.87	7.78	21	32.69	7.55	6.95	8.21	7.59
22	22.01	8.34	8.48	7.83	7.77	22	32.71	7.53	6.93	8.21	7.56
23	21.99	8.33	8.46	7.77	7.76	23	32.71	7.51	6.92	8.20	7.54
24	21.95	8.34	8.46	7.82	7.75	24	32.75	7.49	6.91	8.18	7.53

Table 3 : Drying rate data

Filename: C:\Program Files\Pyris\Data\FYP\AFIQ\lime peel\HTT\220-60min new ratio\79-1\220-60-79-1 TEST 1.tg1d
Operator ID: zalmi/afiq
Sample ID: 220-60-79-1
Comment:
Serial Number: 537N1042910
Data Collected: 4/17/2017 4:13:05 PM
Sample Weight: 9.170 mg
Display Weight: 9.170
Validation
Validated: No
By: |
Date:
Calibration Information
Filename: C:\Program Files\Pyris\Calibrations\Cal 24112016_20C_1.tg1c
Date/Time:
Initial Conditions
Temperature: 40.00 °C
Baseline Filename:
End Condition: Go To Load
Total Points in Run: 4380
Method Steps:
Pre-Run Actions
Start the Run
        Action occurs Immediately
Switch the Gas to Nitrogen at 20.0 ml/min
        Action occurs Immediately
1)   Heat from 40.00°C to 110.00°C at 20.00°C/min

2)   Hold for 10.0 min at 110.00°C

3)   Heat from 110.00°C to 900.00°C at 20.00°C/min

4)   Hold for 20.0 min at 900.00°C
            Switch the Gas to Oxygen at 20.0 ml/min
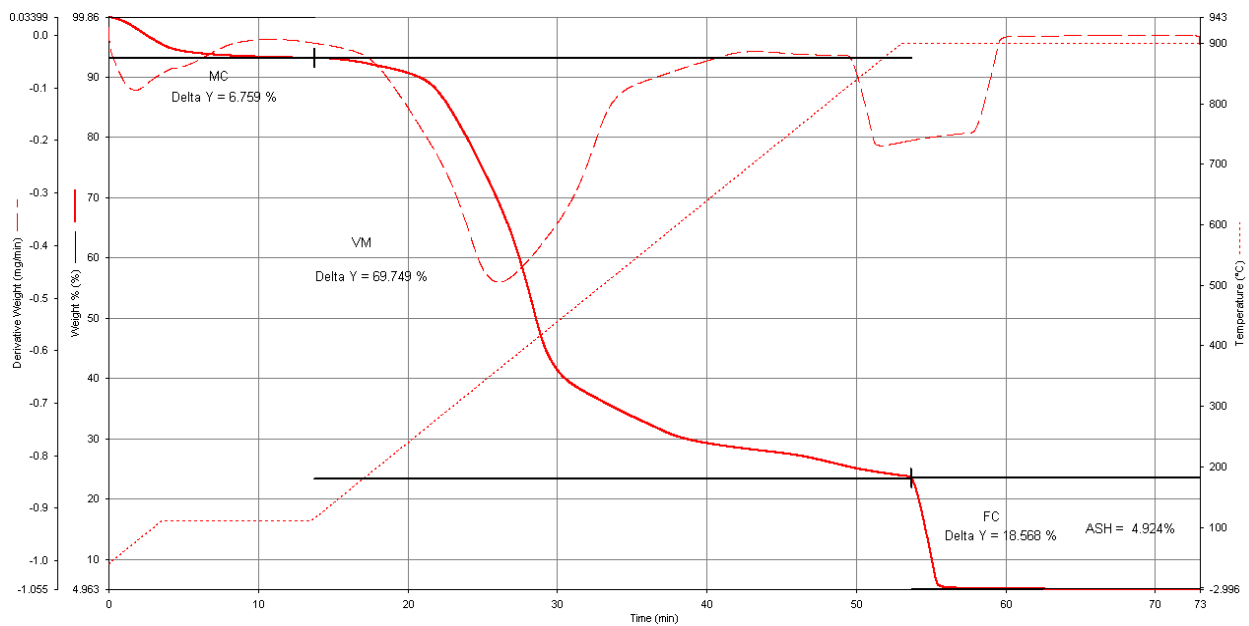   Action occurs Immediately

Table 4 : Thermogravimetric programme and example of the result