

# Effect of Fast Pyrolysis Operating Conditions on Product Yield of Red Meranti Sawdust

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**Abstract** - Fast pyrolysis of red meranti sawdust was carried out in a bench-scale tabular furnace reactor for bio-oil production. In this work, the effect of pyrolysis temperature, N<sub>2</sub> gas flow rate, retention time and feed particle size were studied. Results showed that the bio-oil achieved maximum yield about 63.2 wt. % at the temperature of 450 °C, N<sub>2</sub> flow rate of 25 L/min and retention time for feed particle size of 0.3 mm was 60 min. From analysis, it can be concluded that the temperature was the most influential parameter upon bio-oil yield, followed by N<sub>2</sub> sweeping gas flow rate into the reactor and retention time of biomass in furnace. Feed particles size was insignificantly effect bio-oil yield. Gained bio-oil was analyzed using GC-MS to identify its compounds. Phenolic compound was dominant compound identified in bio-oil.

**Key Words:** Fast Pyrolysis, Operating Parameter, Red Meranti, Bio-oil

## 1. INTRODUCTION

Since 1970s, global energy crisis has begun due to the shortages of petroleum resources. This issue is getting worse due to rapid increase in world's population, industrialization and motorization which lead to a steep rise of petroleum fuel demand. Furthermore, fossil fuels also are regards as a major contribution on greenhouse gas emission, which leads to numerous adverse effects including climate change [1]. The increasing of these major issues have led to a move towards alternative, renewable, sustainable, efficient and cost effective energy sources with lesser gaseous emissions [1]. Biomass is considered as one of a promising energy source and recognized having most similar end products characteristics to that fossil fuel-derived products [2]. There are two fundamental processes of biomass conversion to biofuel: thermo-chemical (combustion, gasification, liquefaction and pyrolysis), or biochemical (fermentation and anaerobic digestion) [3]. Thermo-chemical conversion necessitate much more extreme temperatures and pressures than those applied in bio-chemical conversion method [1]. Fast pyrolysis is a thermo-chemical process, in which, bio-oil is a main product having a great potential as a fuel oil. Fast pyrolysis is conducted on fine particle (< 2mm) at high

temperature (400 to 650 °C)[4], with very high heating rate (> 10 – 200 °C/min) and short vapour residence time (< 2 s) in inert atmosphere.

Malaysia has vast amount of abundance waste which estimated only 24.5% of waste converted to potential energy [5]. Forestry residue is the second largest of waste producer after palm oil industries. Thus, it is crucially important to conduct comprehensive study of conversion of waste to potential energy.

Therefore, in this work, red meranti sawdust (RMS), which is, one of the most significant forestry residue was chosen as biomass in fast pyrolysis experiment. Fast pyrolysis of RMS was carried out in tabular furnace to investigate the effect of pyrolysis operating conditions to bio-oil yield. Parameter operating involved were temperature, N<sub>2</sub> flow rate, feed particle size and retention time.

## 2. MATERIAL AND METHODS

### 2.1 Biomass

The RMS wood used in this study was taken from Sen Peng Sawmill Gambang, Pahang. This sample was collected in form of sawdust which resulted from the waste of wooden products processing. For experimental purpose, RMS particle size was separated by sieve with arithmetic averages size of RMS were 0.30 mm (less than 0.6 mm), 0.89 mm (0.60 to 1.18 mm), 1.59 mm (1.18 to 2.00 mm), 3.00 mm (2.00 – 4.00 mm). Then, RMS feedstock was dried in oven (model RF115) at 105 °C for a few hours duration to minimize the initial moisture. Table -1 list the ultimate and proximate analyses of RMS sample. Ultimate and proximate analyses were carried out according to ASTM D3176 and ASTM E870 - 82(2013), respectively. Component of red meranti was determined according to TAPPI method.

**Table -1:** Ultimate and proximate analyses of RMS

Ultimate analysis <sup>b</sup>	(wt. %)	Proximate analysis <sup>a</sup>	(wt. %)	Component analysis <sup>a</sup>	(wt. %)
C	42.10	Moisture	5.95	Hemicellulose	13.97
H	7.88	Volatile	78.61	Cellulose	51.02
N	0.24	Fixed carbon	15.19	Lignin	29.31
O <sup>c</sup>	49.75	Ash	0.25	Other	5.7
S	0.03				

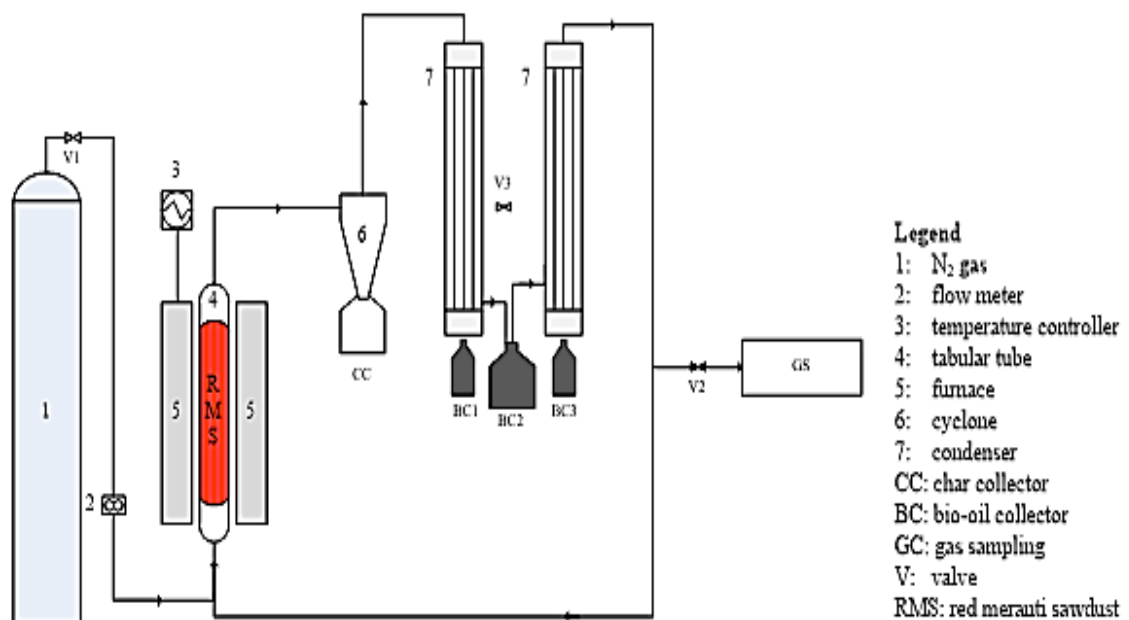
<sup>a</sup> As received

<sup>b</sup> On dry ash free basis

<sup>c</sup> By difference

**Table -2:** Fast pyrolysis reaction conditions

Run	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Temperature (°C)	350	400	450	500	550	600	450	450	450	450	450	450	450	450	450	450	450	450	450	450
Gas flow rate (L/min)	20	20	20	20	20	20	5	10	15	20	25	30	25	25	25	25	25	25	25	25
Retention time (min)	60	60	60	60	60	60	60	60	60	60	60	60	40	60	80	60	60	60	60	60
Arithmetic mean of feed size (mm)	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.89	1.59



**Fig -1:** Schematic diagram of pyrolysis apparatus

## 2.2 Pyrolysis Apparatus

The fast pyrolysis of RMS was carried out in stainless steel tabular furnace reactor. Schematic diagram of pyrolysis apparatus used is shown in Fig -1. This apparatus comprises of vertical tube furnace with bore opening diameter 60 mm and height 300 mm, cyclone, char collector, 2 units of condenser, bio-oil collector, gas flow meter and N<sub>2</sub> gas. N<sub>2</sub> gas was employed as carrier gas and provide inert pyrolysis medium. Prior to experiment, 50 g of RMS was inserted into the furnace tube and head of furnace tube was closed with cap. Temperature of furnace was set to desire temperature at a constant heating rate of 50 °C/min. During pyrolysis process, pyrolysis products were swept out from the furnace tube and passed through the cyclone, in which, larger and heavier particles of char product was separated and collected in the bottle, below the cyclone. After passing through the cyclone, the mixtures of hot pyrolysis products were cooled down by water as coolant agent in two units of condenser. Below these condensers, condensable vapour was collected as bio-oil in bio-oil collector. Each experiment was performed and repeated three times with the experimental error around  $\pm 3$  wt. % and the averaged values were used for analysis.

## 2.3 Pyrolysis Condition

Pyrolysis experiments were conducted according to one-factor-one-time (OFAT) approach as listed in Table 2.

## 2.4 Product Analysis

After each experiment, bio-oil was collected. All bio-oils were mixed well and weighted. Bio-oil then was subjected to GC-MC to analyse its compound. Char was collected from tube furnace and cyclone, mixed and weighted. Gas released was calculated by subtracting the percentages weight of bio-oil and char from 100 wt. %.

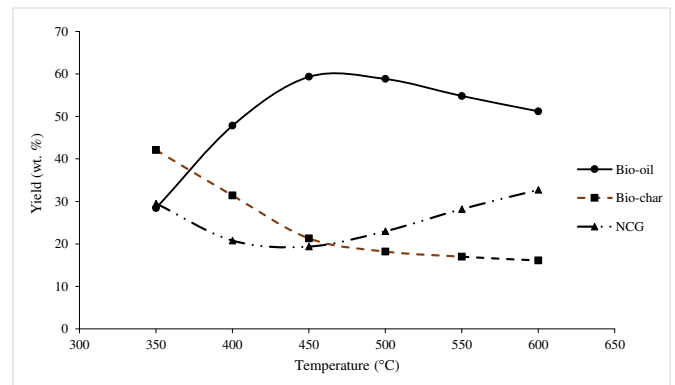
## 3 RESULT AND DISCUSSION

### 3.1 Effect of Temperature

Chart -1 shows bio-oil yield including char and gases product distributions at different pyrolysis process temperature.

As presented in Chart -1, at 350 °C, char formation was highest and bio oil yields was the lowest. Solid collected from the furnace showed that some portion of RMS still not yet fully pyrolysed, indicated that incomplete pyrolysis was occurred on RMS which led to more char formation [6]. However, as temperature increased up to 450 °C, char formation decreased and bio-oil yield increased. The pattern of results indicated that RMS was increasingly pyrolysed and releasing more vapour containing more condensable

compound [7]. At the temperature of 450 °C, bio-oil production achieved maximum yield about 59.3%. This temperature was the most optimum temperature in which large fraction of RMS components been pyrolysed and converted to vapour, and finally condensed as bio-oil.

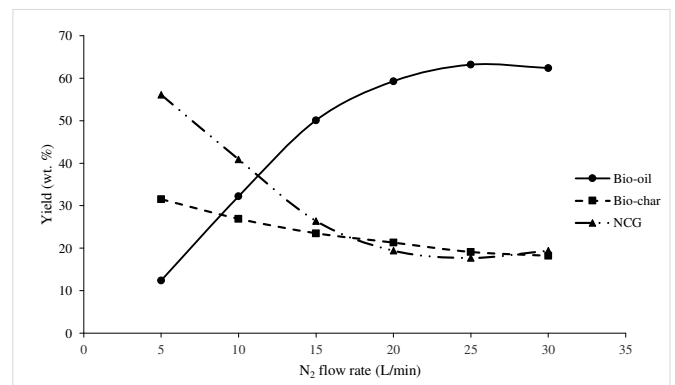


**Chart -1:** Products distribution as a function of pyrolysis reaction temperature at N<sub>2</sub> gas flow rate at 20 L/min, retention time of 60 min and feed size of 0.3 mm.

After 450 °C, both bio-oil and char produced gradually decreased, while gases released increased significantly, until final pyrolysis temperature of 600 °C. This result was attributed to secondary cracking occurred on primary product [7].

### 3.2 Effect of Nitrogen Gas Flow rate

Short vapour residence time is realised by flowing inert gas into the reactor.



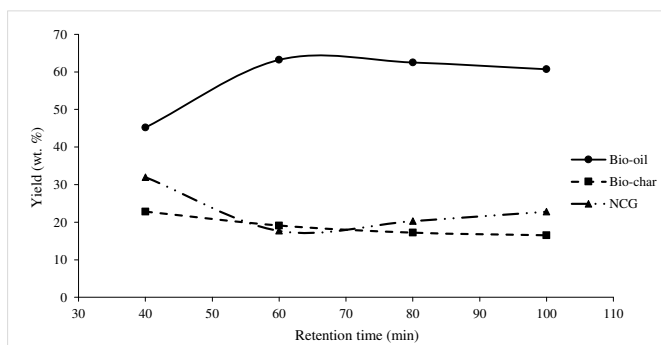
**Chart -2:** Products distribution as a function of sweeping N<sub>2</sub> gas flow rate at a temperature of 450 °C, retention time of 60 min and feed size of 0.3 mm.

As shown in Chart -2, when N<sub>2</sub> gas flow rate was set to 5 L/min, it can be observed that the amount of bio-oil yield was relatively low, while char formation and gas released were high. At this flow rate, N<sub>2</sub> was too slow to sweep out the vapour from the reactor. This condition led to longer vapour

residence time in furnace which finally permits to repolymerisation occurred on unstable pyrolysis vapour, and further resulted in secondary char formation in char pores and increased the amount of gas released [8]. When the flow rate of N<sub>2</sub> was raised up to 25 L/min, bio-oil yield increased rapidly, opposite with the amount of gas release, while char formation gradually decreased. The trend of graph indicated that, as the flow rate of N<sub>2</sub> was raised, shorter vapour residences time was achieved and primary product of pyrolysis can be prevented from undergoing secondary reactions [9]. Collected bio-oil attained highest yield about 63.2% at the flow rate of N<sub>2</sub> gas of 25 L/min. Therefore, the 25 L/min is the optimum flow rate and meets the need of less than 2 s of vapour residence time in reactor. Then, when the flow rate of N<sub>2</sub> increased highly more than 25 L/min, bio-oil yield start decreased, while gas release increased and char formation remain insignificantly change [7][9].

### 3.2 Effect of Retention Time

Result the influence of retention time of RMS in pyrolysis reactor was presented in Chart -3.



**Chart-3:** Products distribution as a function of retention time at a temperature of 450 °C, N<sub>2</sub> gas flow rate at 25 L/min and feed particle size of 0.3 mm.

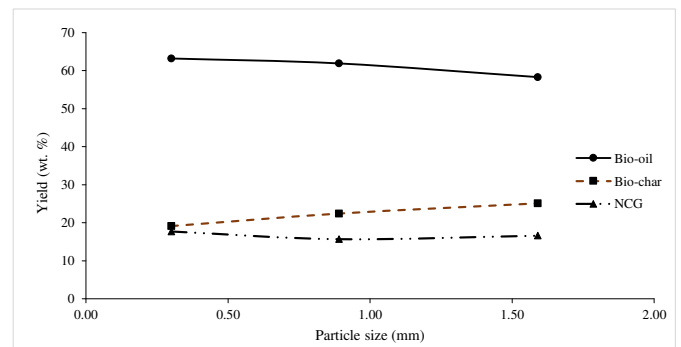
All RMS fraction completely pyrolysed when retention time of RMS was 60 min. Shorter than this period, some fraction of RMS still not completely pyrolysed, while longer, the curve nearly constant indicated that, only unstable bio-oil underwent secondary reaction [10] and lead to releasing more gases.

### 3.3 Effect of Particle Size, D<sub>p</sub>

Feed particles size is another factor influence liquid yield. Result of experiment is presented in Chart -4.

As shown in Chart -4, as the particle size was increased from 0.30 to 0.89 mm, and next to 1.59 mm, amount of bio-oil yield decreased from 63.2 to 61.9% and next to 58.3%, while char formation and gas released continually increased. The

trend of result was influenced by heat transfer effect between RMS particles, because, as the particles size was increased, heat transfer between the particles was decreased and eventually reducing the yield of bio-oil. Larger particle requires more time to heat by intra-particle conduction [11], where eventually lead to slower heating rate and incomplete thermal decomposition, and thereby increase in char and less in vapour yields [12].



**Chart -4:** Products distribution as a function of feed size at a temperature of 450 °C, N<sub>2</sub> gas flow rate of 25 L/min, and retention time of 40 min.

### 3.4 Bio-oil Compound

Bio-oil for GC-MS analysis was taken though Run 17. Main compound identified in bio-oil is listed in Table 3. The major compounds identified in bio-oil were phenolic compounds with the highest peak area was 2,6-dimethoxy-4-(2-propenyl)-phenol (14.2%).

Table -3: Main compound identified in bio-oil

Compound	Area (%)
Phenol, 2-methoxy-4-methyl-	5.8
2,6-dimethoxy-phenol	3.5
2-methoxy-4-(1-propenyl)-, (Z)-phenol	2.9
2-methoxy-4-propyl-phenol	1.4
2,6-dimethoxy-4-(2-propenyl)-phenol	14.2
4-ethyl-2-methoxy-phenol	1.3
2-Methoxy-4-vinylphenol	7.7
1-(4-hydroxy-3-methoxyphenyl)- ethanone	0.9
3,5-Dimethoxy-4-hydroxycinnamaldehyde	3.3
4-Hydroxy-2-methoxycinnamaldehyde	3.5
1,2-Benzenediol	2.3
4-hydroxy-3,5-dimethoxy-benzaldehyde	6.0
4-Methyl-2,5-dimethoxybenzaldehyde	2.2
3-Hydroxy-4-methoxybenzoic acid	4.5
4-Methoxy-4',5'-methylenedioxybiphenyl-2-carboxylic acid	2.1
3,5-Dimethoxy-4-hydroxyphenylacetic acid	1.9
1,6-Anhydro-.beta.-D-glucopyranose (levoglucosan)	8.8

2-Furancarboxaldehyde, 5-(hydroxymethyl)-	4.2
Heptadecane	0.7
5-tert-Butylpyrogallol	0.6
Homovanillyl alcohol	1.1
D-Allose	9.8
1-(4-hydroxy-3,5-dimethoxyphenyl)-ethanone,	1.7

#### 4. CONCLUSION

The optimum conditions for fast pyrolysis process of red meranti sawdust with maximum bio-oil yield of 63.2 % were at the temperature of 450 °C, N<sub>2</sub> flow rate of 25 L/min, retention time of 60 min and particle size of 0.3 mm. Temperature was the most important factor determine the products distribution, followed by N<sub>2</sub> gas flow rate. Through GC-MS analysis, bio-oil component of RMS was dominated by phenolic compound.

#### ACKNOWLEDGEMENT

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