Characterization of asphalt binder containing hydrothermal liquefied composition extracted from food waste

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Abstract. The use of biological wastes to extract an alternative substance to the asphalt binder could potentially reduce the depletion of crude oil. This also could address the environmental pollution resulting from these wastes and develop the asphalt pavement economically and environmentally. Liquefied product extracted from food waste by hydrothermal liquefaction process can be used as an alternative bio-binder in asphalt pavement. This study evaluates the performance of the base asphalt binder of 60/70 pen after adding the hydrothermal liquefaction product of food waste. This involves a set of laboratory trials in liquefying the food waste via hydrothermal process under various selected variables. The physical properties of the base and modified asphalt binder were then evaluated using the penetration, softening point and viscosity test. The results conclude that liquefied food waste (LFW) product has a potential to be used as bio-binder in asphalt pavement.

1. Introduction
Asphalt is a residue from the process of refining crude oil and was used as a binder for the production of asphalt pavement. The decrease in oil reserves and the development of obtaining good fuel quality with low amount of residue have restricted the use of asphalt binder for road application as the cost of production increases. In order to solve this problem, efforts in implementing the usage of non-petroleum sources as alternatives to the existing petroleum-based asphalt have been utilized. This non-petroleum based was characterized as bio-binder and was preferred to be used in asphalt pavement due to its renewability and environmental friendliness [1,2]. Research is currently focused on extracting bio-oil from biomass such as animal waste, castor oil, microalgae, various plant products, etc. [1,3,4-8,14,16]. Other than these biomasses, the disposed food waste is also identified as having potential in generating an alternative binder. Food waste, which comes from various sources including fruit and vegetables, meat and poultry, and is generated daily, has become a new interest for extraction of value-added products such as protein, lipid, gelatin and amino acids in the production of oil and sustainable source of energy [13-15]. Annually, it is estimated that approximately 1.3 billion tons of food waste is generated globally as reported by the United Nation’s Food and Agriculture Organization [17-18]. In the United States, organic waste reaches about 150 million tons per year [12]. In developing Asian countries, the proportion of food waste generated is expected to rise due to sustained population, economic growth and urbanization. For example, the annual production of food wastes in Singapore reached about

790,000 tons in 2014. On the other hand, in Malaysia, the production of food waste was estimated about 15,000 tons per day in 2015 [10-11]. As this becomes a huge problem worldwide due to the shortage of landfills and increase of management cost, the government struggled to develop alternative means to reduce the volume of waste entering landfills. By recycling, this waste will not only conserve the limited landfill space but also help to reduce greenhouse gas emissions. Due to the high content of proteins, fats, carbohydrates, and minerals in food waste, the potential for restoration of high value biological products are of great interest [12]. In 2004, Colas SA has obtained a patent for asphalt binder produced from vegetable oil. Shell Oil Company, in 2007, paved two road sections using asphalt binder processed from vegetable oil [5]. Therefore, this study is an initiative to investigate the potential of converting the liquefied product extracted from mixed food waste such as rice, vegetable, and chicken through hydrothermal liquefaction into binder. The extraction of oil from the food waste has a great potential to be used as an alternative binder for paved road. In this study, the liquefied product was targeted to replace a certain amount of asphalt (60/70 pen) as modified asphalt binder and characterized for the physical properties.

2. Methodology

2.1 Materials

The food waste in this study was collected from household food which consists of rice, vegetables, and chicken. The control asphalt binder of 60/70 penetration grade from Kemaman Bitumen Company was used for the sample preparation and the binder tests were conducted in accordance to Malaysian Public Works Department (PWD) requirement [31]. The physical properties of asphalt binder 60/70 pen were listed as in Table 1.

Table 1. Properties of asphalt 60/70 pen.

Description	Result	Requirement	Specification	Ref.
Penetration at 25 °C (dmm)	66	60-70	ASTM D5	[19]
Softening point (°C)	52.5	49-56	ASTM D36	[20]
Viscosity at 135 °C (Pa·s)	0.7	< 3	ASTM D4402/D4402M	[21]

2.2 Hydrothermal liquefaction of food waste

The hydrothermal liquefaction (HTL) was conducted in batch reactor (stainless steel vessel of 400 ml) and stirred at 200 rpm (Model 2590, Amar Equipment's PVT. LTD. India). The reaction process was run with 40 g of food waste to a fixed volume of distilled water of 100 mL at reaction temperature of 225 °C for 0.5 to 2.5 h reaction time. The different ratios or combination of food waste composition (FWC) i.e. rice, vegetable and chicken (R:V:C) were also studied to find the optimum LFW yield. The time of reaction was referred to as the operation time of the reactor at the required temperature, excluding the heating and cooling time. After the reaction, the reactor was cooled before conducting the separation of liquefied product. As a result of the liquefaction process, the liquefied product was separated from the solid residues (char) by filtration. On the other hand, the water was removed from the product by evaporation using the circulation oven at 110 °C for 15 h. The liquefied food waste (LFW) product yield was calculated using equation (1).

$$\text{Liquefied Food Waste (LFW) yield (wt.\%)} = \frac{\text{weight of liquefied product (g)}}{\text{weight of food waste (g)}} \times 100 \qquad (1)$$

2.3 Preparation of modified asphalt binder
Initially, asphalt binder (60/70 pen) was heated to a temperature of 135°C to melt the binder. The preparation of the modified asphalt binder was done by substituting 5 and 10% of the liquefied product by weight of the asphalt binder. The high shear mixer was used to blend the liquefied product with the control asphalt binder at a constant speed of 1000 rpm at 130°C for 30 min. The speed and temperature of the mixture were determined based on the properties of the liquefied product added to the asphalt binder. In addition, the time of the mixture was selected for 1 h in achieving the required homogeneity between the liquefied product and asphalt binder. The samples were then prepared for the binder tests and compared with the control asphalt binder.

2.4 Penetration test
According to ASTM D5/D5M-13 [19], the penetration test was used to measure the consistency of the asphalt binder sample. The penetration depth of the sample is determined by a distance in tenths of a millimeter that is penetrated by a standard needle loaded with 100 g under constant conditions at a temperature of 25°C for 5s.

2.5 Softening point test
The softening point test was performed for control and modified asphalt binder based on ASTM D36/D36M-14 [20] specifications. This test is important to evaluate the behaviour of asphalt binder at increasing temperature. The sample was poured into the rings and was conditioned in water bath at temperature of 5°C. During the test, the condition of the binder changes from fragile to soft liquid and low viscosity with high temperature.

2.6 Viscosity test
Based on ASTM D4402/D4402M-15 [21], the rotational viscosity meter was used to measure the viscosity of the asphalt binder at high temperatures. The advantage of viscosity measurement is to obtain the internal friction and flow resistance of asphalt. The low reading of the viscosity in units of centipoise (cP) means that the sample has low friction. The aim of measuring the viscosity is to determine the temperature of mixing and compaction of hot asphalt mixture.

2.7 Penetration Index (PI) and Penetration Viscosity Number (PVN)
Penetration index is a measure of the temperature susceptibility of asphalt [29]. Susceptibility to temperature is the change in consistency of asphalt as a function of temperature [27]. Penetration value with the softening point was used to calculate the penetration index (PI). The penetration index can be calculated using equation (2).

$$PI = \frac{(1951.4 - 500 \log P - 20SP)}{(50 \log P - SP - 120.14)} \tag{2}$$

Where:

PI is penetration index
P is penetration value (dmm) @ 25^{O}C
SP is softening point value (^{O}C)

The PVN result depends on penetration at 25°C and viscosity at 135°C which was adopted as in standard specifications for paving asphalt [30]. The PVN can be calculated using equation (3).

$$PVN = (-1.5)\ x\ \frac{(4.258 - 0.7967 \log P - \log V)}{(0.795 - 0.1858 \log P)} \tag{3}$$

Where:

PVN is penetration viscosity number

P is penetration value (dmm) @ 25^{O}C
V is viscosity (centipoise) @ 135^{O}C

3. Results and discussion

3.1 Liquefaction of food waste

3.1.1 The effect of the reaction time on the liquefied product

The effect of reaction time on hydrothermal liquefaction (HTL) of food waste at 225 °C is depicted in Figure1. Overall, as the time increases from 0.5 h to 2.5 h, the LFW yield increases from 9.7 wt.% to 26.7 wt.%. The results show increment of the LFW yield with reaction time, particularly after 1 h reaction at 12.5 wt.%. At this stage, the trend of the LFW yield involves the first phase of reaction as the components of the food waste was continuously being liquefied. As the time increases to 1.5 h, the LFW yield is significantly increased to 24 wt.% because more organic materials in food waste were converted into the liquefied product [22]. The results show that the formation of the LFW has further decomposed into lighter and small chemical component and gases. Therefore, further increases in the reaction time lead to the increase of gas yield as well as the aqueous phase [22, 23]. It was observed that the HTL reaction formed less viscous product after 1.5 h compared to 1 h reaction time. On the other hand, long reaction time (1.5 h to 2.5 h) shows slow increment of LFW yield due to optimum conversion of the food waste to mainly liquid and char product. In this study, the reaction time of 1 h was selected due to the high viscosity of the liquefied product, which is suitable for mixing with asphalt as to enhance the asphalt binder properties.

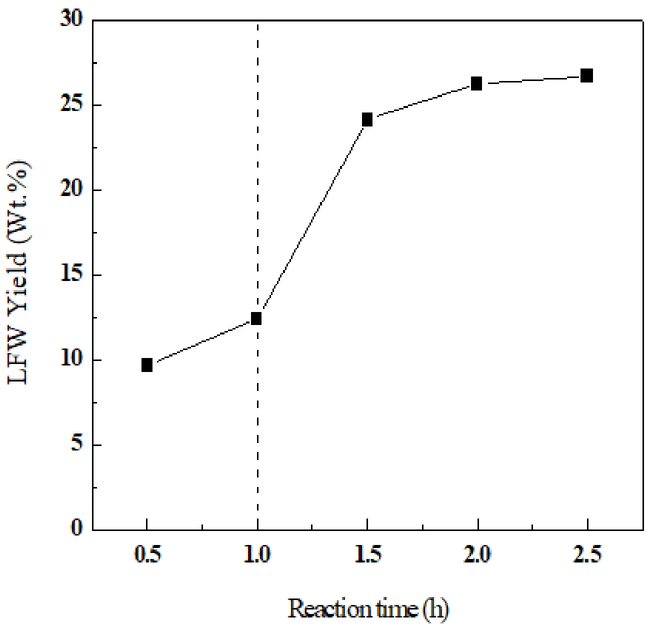

Figure 1. The effect of reaction time at 225 °C, FW/W (40:100) and FWC (2:1:1).

3.1.2 The effect of the food waste composition on the liquefied product

Figure 2 shows the percentages of LFW yield based on six different ratios of rice, vegetables and chicken. Based on the result, the increase in the proportion of chicken and rice compared to vegetables led to an increase in the liquefied natural product. The result was shown by the high LFW yield (14.18 wt.%) obtained by the food waste ratio of 2:1:2. High LFW yield was obtained in the presence of rice or chicken as shown by the waste composition ratio of 2:1:1 and 1:1:2. These substances are rich in lipid and complex carbohydrates such as starch, cellulose and amino acids that can be converted into biological substances such as biodiesel and bioethanol [14, 24]. Low LFW yield was produced with increase of vegetable in the waste mixture as shown by the waste composition of 1:2:1 yielding 9.2 wt.% of LFW. The same observation can be seen for other ratios i.e. 1:2:2 (11.13 wt.%) and 2:2:1 (12.83 wt.%) waste composition, particularly with the increase in the composition of vegetable. This is because vegetables contain a high percentage of dietary fibre (35-60%), which is classified as soluble and non-soluble fibre consisting of non-starchy sugars, pectin, cellulose, hemicellulose, and lignin compared to rice and chicken that contains high lipid and complex carbohydrates [25]. Therefore, the increase in the proportion of raw materials that contain lipid and carbohydrates leads to an increase in the yield of the LFW.

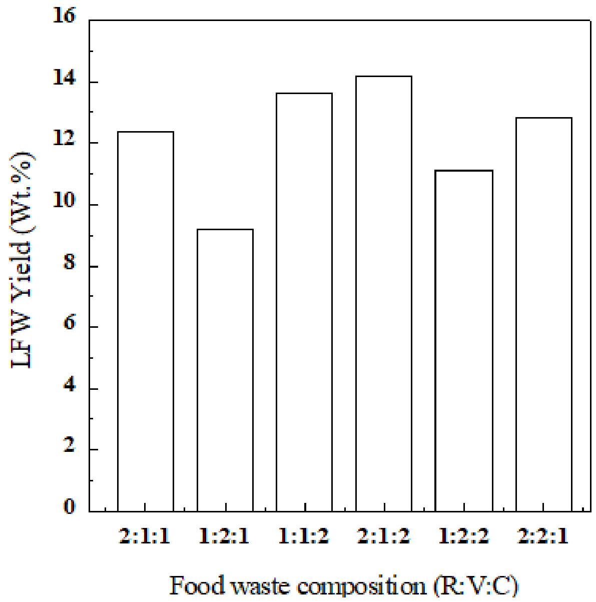

Figure 2. The effect of FWC at 225 °C, FW/W (40/100) and reaction time 1h.

3.2 Penetration

The penetration shows the consistency and relative viscosity of asphalt [26]. Figure 3 presents the penetration at 25 °C for conventional 60/70 pen asphalt and modified 60/70 pen with LFW at 5 and 10%. It can be clearly observed that penetration value of the modified binder with 5% LFW decreases with the increase of LFW dosage. The penetration value decreases from 66 dmm to 61 dmm and this indicates that replacement of LFW slightly hardens the binder [27]. On the other hand, 10% LFW content increases the penetration value to 70 dmm, thus showing that further addition of LFW softens the asphalt. Nevertheless, the penetration value obtained from this test is still acceptable according to the specification, which presents that the replacement of LFW gives small effect on the consistency of the asphalt binder.

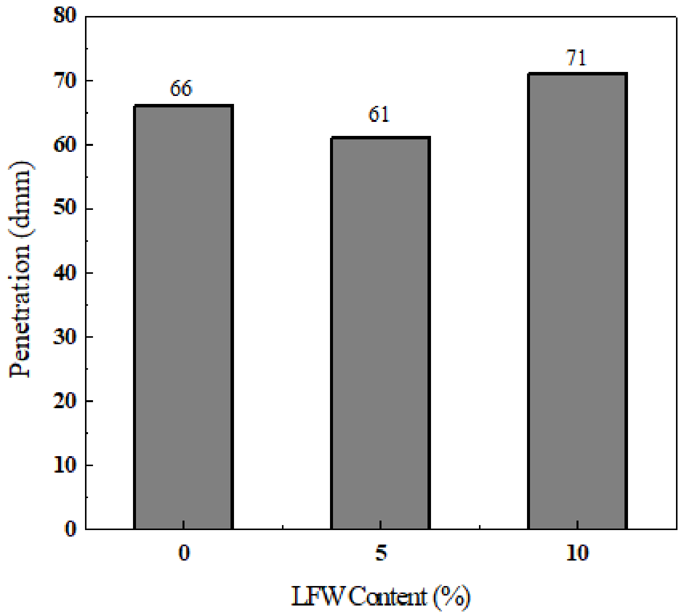

Figure 3. Penetration test results for LFW modified asphalt.

3.3 Softening point

Figure 4 shows the softening point of LFW modified asphalt binder. It can be seen from the figure that the softening point value increases from 52.5°C to 54.5°C for 5% LFW content. When the LFW dosage increases to 10%, the softening point dropped slightly to 53.5°C, but is still higher than control asphalt binder. Further addition of 10% LFW reduces the ability of asphalt to sustain higher temperature and this result was relatable with the results on penetration value of modified asphalt binder [27].

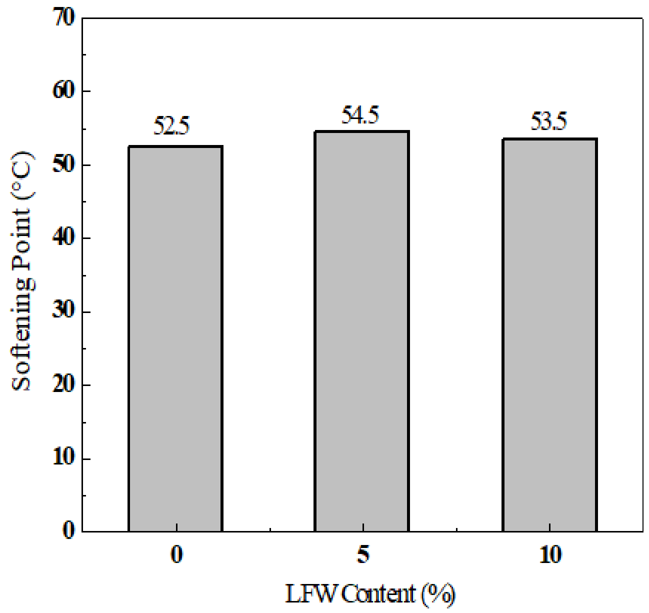

Figure 4. Softening point test results for LFW modified asphalt.

3.4 Viscosity

The viscosity is an important factor in the asphalt binder modification which reflects its pumping ability during mixing with aggregates [28]. From Figure 5, it can clearly be observed that the viscosity of LFW modified asphalt binder at 135°C is similar to the control asphalt 60/70 pen, which at 0.7 Pa.s. As the temperature increases to 165°C, the modified asphalt binder slightly reduced its viscosity for 5 and 10% LFW amount. This shows that the substitution of LFW product in asphalt binder produces a comparable result, where the properties of original asphalt are not much affected with the replacement of 5 and 10% LFW by weight of the asphalt binder.

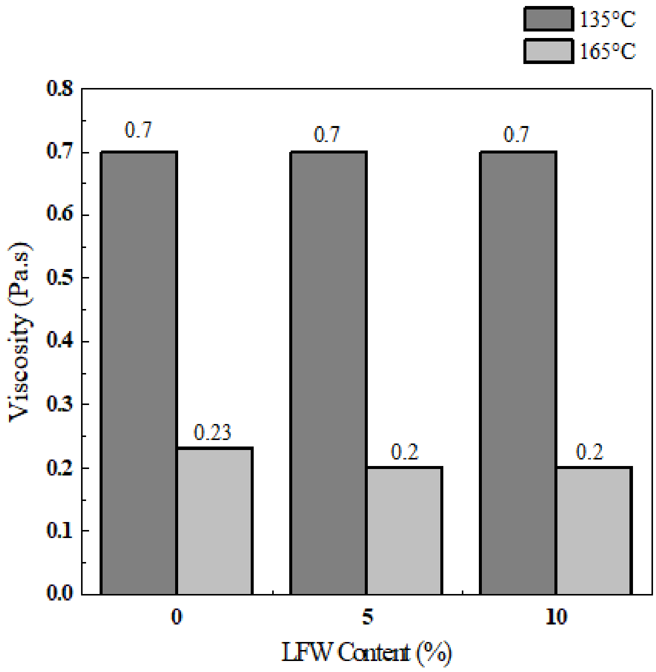

Figure 5. Viscosity test results for LFW modified asphalt.

3.5 Penetration Index (PI) and Penetration Viscosity Number (PVN)

Table 2 shows the PI and PVN value of LFW modified asphalt binder. It can be seen that the increase in LFW content from 0% to 10% led to an increase in the penetration index from 0.1 to 0.55. This indicates that the addition of LFW in asphalt resembles the temperature susceptibility compared with the control asphalt binder. In addition, the PI result is relatable with the PVN value, although 5% LFW content shows small decrement. The PVN value of 5% LFW modified asphalt reduces from 0.12 of control asphalt to 0.03 and increases to 0.19 for 10% LFW content. This shows that the binders produced are less susceptible to temperature changes and resemble the control asphalt. In other words, the LFW has a potential to replace the conventional asphalt binder up to a certain amount.

Table 2. PI and PVN value of LFW modified asphalt binder.

Liquefied food waste (LFW) composition (%)	**Penetration Index (PI)**	**PVN value**
0	0.1	0.12
5	0.37	0.03
10	0.55	0.19

4. Conclusion

This study evaluates the potential of using liquefied food waste, LFW, in asphalt binder. The addition of LFW provides small difference in the value of penetration and softening point compared to the control asphalt binder. The same observation was also obtained for viscosity, PI and PVN values where the difference was relatively low. Therefore, it can be concluded that LFW used for the binder replacement resembles or has the characteristics of asphalt binder. Further study on the chemical characterization should be conducted to verify the similarity of these materials.

5. References

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