# EFFECT OF LIQUEFIED FOOD WASTE ON ASPHALT MIXTURE PERFORMANCE

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# DEDICATION

♥ *To My parents, wife and friends for their support and love* ♥

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# ABSTRACT

Considerable environmental concern regarding increased food wastage caused by population and economic growth has been raised worldwide. Thus, determining an alternative food waste recycling method for construction purposes is a challenge. This research evaluates a liquefied bio-product recovered from the hydrothermal liquefaction of food waste as a potential non-petroleum-based binder in asphalt pavement. Numerous parameters were evaluated to optimize the liquefaction reaction for the enhancement of the liquefied food waste (LFW) product recovered from the process. Next, LFW was used to substitute various portions of conventional asphalt binders 60/70 PEN (i.e., 5%, 10%, 15%, 20% and 30%) from the total binder weight. Then, their storage stability, physical, and rheological properties were assessed. Chemical properties, thermal decomposition, functional groups, and surface morphology analysis for LFW, conventional and modified asphalt binders were also determined. LFW provides the asphalt binder with improved rheological properties reflected by the enhanced rutting resistance for the modified asphalt binder with high performance grade. The FT-IR spectra of the LFW modified asphalt binder showed no new peak which indicates no chemical reaction occurred between asphalt binder and LFW. Morphological analysis revealed the presence of LFW boosted the quantity of heteroatoms and the polarity of the asphalt binder, which in turn is responsible for enhancing the adhesion properties between asphalt binder and aggregate. In addition, LFW asphalt mixture recorded featured performance for the creep resistance, which appeared by the highest creep stiffness with low permanent deformation as compared to the conventional mixture. This supported by the lower rutting depth measured for the modified samples compared to the conventional sample. Overall, the findings show that the LFW modified asphalt meets the standards specified for paving material and the environmental impact requirement.

# ABSTRAK

Keprihatinan yang tinggi terhadap alam sekitar mengenai peningkatan pembaziran makanan yang disebabkan oleh pertumbuhan penduduk dan ekonomi telah meningkat di seluruh dunia. Oleh itu, penentuan kaedah alternatif kitar semula sisa makanan untuk tujuan pembinaan adalah satu cabaran. Penyelidikan ini menilai bio-produk cecair yang diperoleh daripada pencairan hidrotermal sisa makanan yang berpotensi sebagai pengikat bukan berasaskan petroleum dalam turapan asfalt. Pelbagai parameter telah dinilai untuk mengoptimumkan tindak balas pencairan bagi peningkatan produk sisa makanan yang dicairkan (LFW) yang terhasil daripada proses tersebut. Seterusnya, LFW telah digunakan untuk menggantikan beberapa kandungan pengikat asfalt konvensional 60/70 PEN (iaitu 5%, 10%, 15%, 20% dan 30%) daripada jumlah berat pengikat. Kemudian, stabiliti penyimpanan, sifat fizikal dan reologi mereka telah dinilai. Sifat kimia, penguraian haba, kumpulan berangkap, dan analisis morfologi permukaan untuk LFW, pengikat konvensional dan asfalt terubahsuai juga ditentukan. LFW memberi pengikat asfalt dengan sifat reologi yang lebih baik yang direfleksi daripada peningkatan daya ketahanan aluran bagi pengikat asfalt yang diubahsuai dengan gred prestasi yang tinggi. Spektrum FT-IR bagi pengikat asfalt terubahsuai dengan LFW menunjukkan tiada puncak baru yang menunjukkan tiada tindak balas kimia berlaku antara pengikat asfalt dan LFW. Analisis morfologi mendedahkan kehadiran LFW telah meninggikan kuantiti heteroatom dan polariti pengikat asfalt, yang mana bertanggungjawab untuk meningkatkan sifat-sifat lekatan antara pengikat asfalt dan agregat. Sebagai tambahan, campuran asfalt LFW telah mencatat prestasi yang unggul untuk rintangan rayapan, di mana boleh dilihat dengan kekukuhan rayapan yang tinggi dengan deformasi kekal yang rendah berbanding dengan campuran konvensional. Ini disokong oleh kedalaman aluran yang rendah bagi sampel terubahsuai berbanding dengan sampel konvensional. Secara keseluruhan, hasil kajian menunjukkan bahawa asfalt terubahsuai dengan LFW memenuhi spesifikasi standard untuk bahan turapan dan keperluan terhadap kesan persekitaran.

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| | | |
|---|---|---|
| AASHTO | | American Association of State Highway and Transportation Officials |
| AC14 | - | Asphaltic Concrete of Nominal Aggregate Size 14 mm |
| ACV | - | Aggregate Crushing Value |
| AFM | - | Atomic Force Microscopy |
| AIV | - | Aggregate Impact Value |
| ANOVA | - | Analysis of Variance |
| APA | - | Asphalt Pavement Analyser |
| ASTM | - | American Society for Testing and Materials |
| BBR | - | Bending Beam Rheometer |
| BS EN | - | British Adoption of a European Standard |
| BP | - | Boiling Point |
| AH-50 | - | Aryl Hydrocarbon Asphalt-50 |
| CHNS | - | Carbon, Hydrogen, Nitrogen, and Sulphur |
| CSM | - | Creep Stiffness Modulus |
| CSS | - | Creep Strain Slope |
| DSR | - | Dynamic Shear Rheometer |
| DWT | - | Double Wheel Tracker |
| EI | - | Elongation Index |
| FESEM | - | Field Emission Scanning Electron Microscope |
| FI | - | Flakiness Index |
| FTIR | - | Fourier Transform Infrared |
| GC–MS | - | Gas Chromatograph-Mass Spectrometer |
| Gmm | - | Maximum Specific Gravity |
| HMA | - | Hot Mix Asphalt |
| IDT | - | Initial Decomposition Temperature |
| ITS | - | Indirect Tensile Strength |
| JKR | - | Jabatan Kerja Raya |

| | | |
|---|---|---|
| KBC | - | Kemaman Bitumen Company |
| LAAV | - | Los Angeles Abrasion Value |
| LAS | - | Linear Amplitude Sweep |
| LMS | - | Large Molecular Size |
| LTA | - | Long-Term Ageing |
| LVDT | - | Linear Variable Differential Transducer |
| MMS | - | Medium Molecular Size |
| MQ | - | Marshall Quotient |
| $M_R$ | - | Resilient Modulus |
| OBC | - | Optimum Bitumen Content |
| PAV | - | Pressure Ageing Vessel |
| Pen. | - | Penetration |
| PI | - | Penetration Index |
| PG | - | Performance Grade |
| RRL | - | Road Research Laboratory |
| RV | - | Rotational Viscometer |
| SG | - | Specific Gravity |
| STA | - | Short-Term Ageing |
| TGA | - | Thermogravimetric Analysis |
| DTG | - | Derivative Thermogravimetry |
| TG-FTIR | - | Thermogravimetric- Fourier Transform Infrared |
| TMD | - | Theoretical Maximum Density |
| TSR | - | Tensile Strength Ratio |
| UA | - | Unaged |
| VA | - | Virgin Asphalt |
| VFA | - | Voids Filled with Asphalt |
| $V_S$ | - | Volume of Water Absorbed |
| VTM | - | Void in Total Mix |
| $V_V$ | - | Volume of Voids |
| WCO | - | Waste Cooking Oil |

| | | |
|---|---|---|
| WEO | - | Waste Engine Oil |
| WVO | - | Waste Vegetable Oil |
| FAO | - | The Food and Agriculture Organization |
| HTL | - | Hydrothermal Liquefaction |
| LFW | - | Liquefied Food Waste |
| R | - | Rice |
| V | - | Vegetable |
| C | - | Chicken |
| TCLP | - | The Toxicity Characteristic Leaching Procedure |
| FSC | - | Food Supply Chain |
| FWC | - | Food Waste Composition |
| UK | - | United Kingdom |
| $CO_2$ | - | Carbon Dioxide |
| $CH_4$ | - | Methane |
| $OH^-$ | - | Hydroxide |
| $H^-$ | - | Hydrogen |
| $H_o$ | - | Null Hypothesis |
| SARA | - | Saturates, Aromatics, Resin, Asphaltene |
| SCG | - | Spent Coffee Ground |
| SBS | - | Styrene–Butadiene–Styrene |
| WCO | - | Waste Cooking Oil |
| DWB | - | Dewatered Wood Bio-Oil |
| PMB | - | Polymer Modified Wood Bio-Oil |
| PWD | - | Malaysian Public Works Department |
| OB | - | Original Bio-Oil |
| WVO | - | Waste Vegetable Oil |
| WA | - | Water Absorption |
| PKO-p | - | Palm Kernel Oil Polyol |

## LIST OF SYMBOLS

| | | |
|---|---|---|
| % | - | Percentage |
| cm | - | Centimetre |
| $cm^{-1}$ | - | Reciprocal Wavelength |
| $cm^2$ | - | Square Centimetre |
| $cm^3$ | - | Cubic Centimetre |
| cP | - | Centipoise |
| dmm | - | Decimillimetre |
| ε | - | Strain |
| g | - | Gram |
| G* | - | Complex Shear Modulus |
| hr | - | Hour |
| Hz | - | Hertz |
| kg | - | Kilogram |
| km | - | Kilometre |
| kPa | - | Kilo Pascal |
| L | - | Litre |
| mg | - | Milligram |
| mL | - | Millilitre |
| $mm^2$ | - | Millimetre Square |
| MPa | - | Mega Pascal |
| N | - | Newton |
| nm | - | Nanometre |
| °C | - | Celsius |
| Pa.s | - | Pascal Second |
| rpm | - | Revolution Per Minute |
| sec | - | Second |
| δ | - | Phase Angle |
| θ | - | Angle |
| μ | - | Poisson Ratio |
| μm | - | Micrometre |
| σ | - | Stress |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Asphalt is an essential composition of bituminous pavements that affects their performance. The increasing demand for petroleum asphalt in the road construction industry has raised long-term concern. The global annual demand for asphalt was estimated on the basis of the amount (i.e., 110 million metric tons) spent on asphalt pavements' construction, preservation, and maintenance (García *et al* ., 2010). Therefore, considering the present issues on petroleum-based asphalt, introducing non-petroleum sources as alternative binders has become important. The use of non-petroleum-based oils is preferred because it is more environmentally friendly, has extensive sources, and is renewable compared with petroleum-based asphalt (Somé *et al*., 2016). Non-petroleum-based oils are also expected to become more economically attractive with the continuous increase in oil price. Numerous biomass materials, including animal waste, microalgae, corn stover, tea and coffee residue, urban yard waste, soybeans, and rapeseed, can be used for generating bio-binder (Zhang *et al*., 2017). Other than that, the use of food waste has also showed potentials for developing a new type of bio-binder as an alternative binder in asphalt pavement. Food waste that resulted from numerous sources, such as fruit, vegetables, poultry, and meat, is generated daily and has been the focus for deriving value-added products, including protein, gelatin, amino acids, and lipid, for producing oil, as well as sustainable energy source (Karmee, 2016). According to the Food and Agriculture Organisation of the United Nations, almost 1.3 billion tonnes of foods are lost or wasted in the food supply chain because of spoilage or expiry, as well as poor stock management (Kaushik *et al*., 2014).

In 25 years, the amount of food waste, particularly in Asian countries, is expected to increase because of population and economic growth. The amount of annual urban food waste in Asian countries can increase from 278 million tonnes in 2005 to 416 million tonnes in 2025 (Kiran *et al*., 2014). For example, the annual food waste production in Singapore in 2014 was approximately 790,000 tons, whereas it was estimated around 15,000 tons per day in Malaysia in 2015 (Kaushik *et al*., 2014). A study by Melikoglu *et al*., (2013) stated that every year, restaurants, supermarkets, and convenience stores in the United States dispose at least 35 million tons of edible food, which amounts to approximately $30 billion. This finding is a major global problem considering the landfill shortage and increased management cost that caused the government to struggle in creating alternatives to reduce the volume of waste that enters landfills. Waste recycling can help to conserve limited landfill space, as well as decrease greenhouse gas emission, including methane, which causes global warming. In addition to environmental challenges, complications concerning food waste composition are inherent; thus, food waste becomes an attractive source of value-added products (Pham *et al*., 2015).

The use of thermal conversion technology is an innovative waste recycling method, specifically in converting biomass into bio-oil. Numerous thermo–chemical conversion technologies, such as gasification, pyrolysis, hydrothermal liquefaction (HTL), torrefaction, and direct combustion, can be used for biomass conversion (Ong *et al*., 2019). HTL is a promising technique for converting biomass into liquefied products using hot, pressurised water to break the chemical structure into major liquid components. It is a wet biomass processing technique that cost-effectively bypasses energy-intensive drying (Mathimani and Mallick, 2019). In other words, this process can be used for biomass with high moisture content and does not require pre-drying. To date, innovations in the sustainable and optimal use of biomass have enhanced the study on the potential usage of the highly viscous product generated from HTL for engineering application as it requires fewer processes during production compared with bio-oil. This study focused on the liquefied product obtained from food waste using hydrothermal process. The use of liquefied food waste (LFW) product versus petroleum-based binder as an alternative binder in asphalt pavement was evaluated. Parameters that influence LFW yield were evaluated to optimize liquefaction, and the product was characterised for physico–chemical properties. In addition, the LFW was introduced to asphalt binder and evaluated for physical and chemical properties followed by the mechanical properties of the modified asphalt mixture with LFW.

## 1.2 Problem Statement

The modification of binders in asphalt pavement is one of the approaches to improve their performance and consequently, that of asphalt mixtures. Various types of modifiers have been employed in asphalt binders to improve the properties of asphalt mixtures, particularly with regard to their resistance to aging, cracks due to fatigue and thermal conditions, moisture-induced damage and permanent deformation. Nowadays, reprocessing of waste materials is a growing technology that must be continuously improved by researching new solutions for waste recycling to increase the amount of waste reused. The use of waste materials has turned into an important issue in asphalt modification to reduce energy consumption as well as consider environmental aspects due to the decrease in natural resources and the increase in road construction activities. Among the modifiers used, bio-oil that is produced from various types of biomass wastes is significant to improve the properties of the asphalt bonding. For example, the use of oak wood oil as an alternative to asphalt binder showed that the rheological properties of the alternative asphalt are similar and comparable to the base asphalt (Raouf and Williams, 2010).

In addition, many researchers mentioned that the bio-oil generated from the renewable biomass is similar to the asphalt binder in terms of elasticity, viscosity, color, and chemical composition, and therefore it can be used as a partial substitute to the binder (Girimath and Singh, 2019). Fini *et al*., (2012) studied the high and low temperature performance of modified asphalt using bio-oil produced from swine manure. The results showed that adding bio-oil improved the low temperature performance, while negatively affecting the high temperature performance of the asphalt binder. Another study by Sun *et al*., (2016) showed that the addition of bio-oil produced from waste cooking oil reduced high temperature performance, while at low temperature performance the results showed a significant improvement of the asphalt binder.

Other than that, food waste also among the biomass that is an important source to produce bio-oil which is a potential candidate for improving asphalt binder properties. Factors that encourage the use of food waste include its availability in large quantities in addition to environmental and economic factors. Annually 1.4 billion hectares of fertile land, equivalent to 28% of all agricultural land around the world, are used to produce food that is wasted or lost. Regardless of the loss of food resources, one of the causes of greenhouse gas (GHG) emissions is the accumulation of approximately 3.3 billion tons of carbon dioxide annually as a result of the carbon impact of food waste (Paritosh *et al.*, 2017). Food waste, which is a type of municipal solid waste, is incinerated (Pattnaik and Reddy, 2010) or thrown into landfills in open areas and thus causes serious environmental and health damage. The process of burning food waste, which is characterized by a high level of moisture, results in the release of dioxins, which causes serious health damage because dioxins are highly toxic chemical compounds (Katami *et al.*, 2004).

Statistics from the Solid Waste Corporation of Malaysia show that in 2015, food waste in Malaysia reached 15,000 tons daily, and a household throws away an average of around 0.5–0.8 kg of uneaten food per day. This problem is expected to increase because Malaysia's population is estimated to reach 33.4 and 37.4 million by 2020 and 2030, respectively. Hence, several researchers have studied the possibility of using food waste in many industrial applications. One of them is the use of the liquefied product extracted from food waste as an alternative material for asphalt binder. Therefore, further research is vital for evaluating the potential of using LFW as a sustainable source of binder for asphalt pavement.

## 1.3 Aim and Objectives

The aim of this research is to produce LFW modified binder in asphalt pavement generated from food waste. The objectives are as follows:

1. To establish the procedures involved in optimising the conversion of food waste into a quality liquefied product.
2. To characterise the physical and chemical properties of the liquefied product obtained from food waste.

3. To determine the physical, chemical, microstructural and rheological properties of LFW-modified asphalt binder at various percentages.
4. To determine the engineering properties of LFW-modified asphalt mixture for unaged and aging conditions (short- and long-term aging).

## 1.4 Scope of Research

This research focuses on the effect of liquefied product from food waste as a binder in asphalt mixture. LFW yields were collected from various ratios of food waste composition based on that of rice to vegetable to chicken (R:V:C). Various percentages of LFW, i.e. 5%, 10%, 15%, 20% and 30% by mass of the binder, were used and compared with conventional asphalt binder. The aggregate was obtained from the Hanson Quarry, Kulai, Johor, Malaysia. The 60/70 PEN asphalt binder was supplied by the Kemaman Bitumen Company, Malaysia. The laboratory works were conducted to evaluate the asphalt properties according to the American Society for Testing and Materials (ASTM) standards, American Association of State Highway and Transportation Officials (AASHTO), Malaysian Public Works Department, and British adoption of a European standard (BS EN). The laboratory tests for the asphalt binder include penetration, softening point, viscosity, ductility, storage stability, bending beam rheometer and dynamic shear rheometer. In addition, the microstructural characterisation of the asphalt binder was performed using contact angle test, atomic force microscopy, Fourier transform infrared and thermogravimetric analysis. The results of the assessment enabled the selection of an optimum LFW content. The asphalt mixtures were then assessed using the optimum content of the LFW selected for binder modification in terms of Marshall properties, resilient modulus, creep stiffness, indirect tensile strength, moisture damage (TSR) and rutting. The asphalt mixture containing LFW was also subjected to the toxicity characteristic leaching procedure (TCLP) to assess the potential risk of heavy metals leaching into the soil and ground water. All the laboratory tests were conducted at the Transportation Laboratory, Chemical Laboratory and Central Laboratory, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia.

## 1.5 Significance of Research

Regular asphalt binder is usually a residue obtained from petroleum distillation. Stringent environmental regulations, dwindling petroleum resources and modifications to refining for increasing fuel quantity whilst minimising asphalt residue have increased the cost of asphalt binder. As a result, non-petroleum alternatives such as bio-oil have become more significant. The liquefied product yielded from food waste that resembles the properties of asphalt binder could potentially become an environment-friendly binder for asphalt pavement. Food waste can have an adverse effect when improperly managed and disposed. Effective waste management via recycling into modified asphalt binder as paving materials can provide substantial environmental and economic advantages. Environmentally, recycling this abundant food waste is an effective, sustainable endeavour which diminishes the amount of waste deposited in landfills, decreases the expenditure of natural resources and conserves the ecosystem. Economically, the use of liquefied product from the food waste as a binder could favourably limit the cost of road construction. Therefore, this study provides a detailed verification of this potential binder as a road paving material from the engineering perspective.

## 1.6 Outline of the Thesis

This thesis consists of seven chapters, which are briefly outlined as follows:

**Chapter 1** provides a broad introduction and background along with descriptions of the study problem, aim, scope and significance.

**Chapter 2** reviews the published research, encompassing studies performed by leading researchers in the field of bio-oil-modified asphalt binder. It describes in detail the testing procedures employed and the factors of the rheological and microstructural characteristics of asphalt binder.

**Chapter 3** details the research plan and procedure, encompassing three stages of work. It discusses the tasks involved in each stage, including the preparation and testing of raw materials and the design of various mixtures.

**Chapter 4** presents the results of LFW production tests, indicating the factors of production and yield, and the characterisation of the liquefied product (LFW).

**Chapter 5** analyses in detail the tested variables to determine the effect of LFW on the chemical, physical, microstructural and rheological characteristics of modified asphalt binder.

**Chapter 6** discusses the results of mechanical properties and the toxicity of the conventional and modified asphalt mixtures containing LFW. These properties include resilient modulus, creep stiffness, rutting, indirect tensile strength, moisture damage and TCLP.

**Chapter 7** covers the conclusions and recommendations for future research.

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