Jurnal
Teknologi

Full Paper

THE POTENTIAL OF WASTE COOKING OIL AS BIO-ASPHALT FOR ALTERNATIVE BINDER – AN OVERVIEW

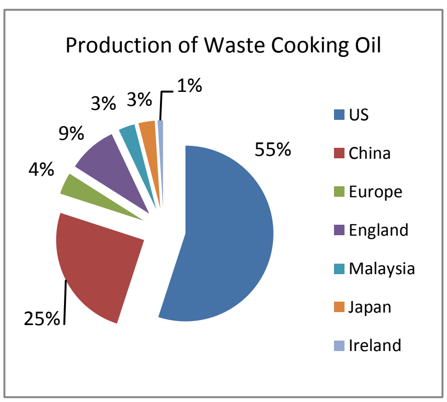
Wan Nur Aifa Wan Azahar[a], Mastura Bujang[a], Ramadhansyah Putra Jaya[a,*], Mohd Rosli Hainin[a], Azman Mohamed[a], Norzita Ngadi[b], Dewi Sri Jayanti[c]

[a]Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Department of Chemical Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[c]Department of Agricultural Engineering, Faculty of Agriculture, Universitas Syiah Kuala, 23111 Darussalam, Banda Aceh, Indonesia

Article history
Received
30th April 2015
Received in revised form
27th August 2015
Accepted
1st October 2015

*Corresponding author
ramadhansyah@utm.my

Graphical abstract



Abstract

Enormous quantity of waste products from by-products of frying activity could cause negative impact if not properly managed and disposed. Therefore, recyclability of Waste Cooking Oil (WCO) in binder modification to produce bio-asphalt can be a sustainable ways to minimize waste dumping while at the same time to reduce the usage of natural resources. Bio-asphalt can be described as alternative asphalt binder which differs from conventional asphalt in terms of strength and durability. This review has highlighted the potential of bio-binder to replace with conventional binder by the addition of waste cooking oil in the mixture.

Keywords: Recyclability; waste cooking oil; bio-asphalt; alternative asphalt binder

1.0 INTRODUCTION

High initial cost of bituminous asphalt binder, reduction supply of crude oil where bitumen is derived and the increased of environmental regulation to sustain and promote green technology in pavement constructions has triggered an initiative to find an alternative binders to replace with the conventional binders. The encouragement for green highlight issues of sustainability has prompted the researches in highway industry to produce new asphalt binder known as bio-asphalt. Bio-asphalt can be categorized as one another optional for asphalt binder made from natural resources which contribute to the environmental benefits. The reduction rate of oil petroleum production through refining process has affected the supply of bitumen which is obtained from a residue of crude oil process.

Thus, the industry has started to explore another opportunity in order to produce an alternative binder to minimize the dependencies on petroleum-based asphalt. For decades, the findings from research industry have succeeded to prove the biomass or bio-waste products as a great potential source to produce bio-asphalt [1-3]. As a result, the recyclability of bio waste product can minimize the landfill areas for waste dumping and emission of greenhouse gases by substituting this bio waste into conventional binder to produce bio-asphalt [1-2].

Therefore, the production of bio-binder from Waste Cooking Oil (WCO) is proposed to response with the issues that the industry currently facing which includes, the high cost of binder price based on the world market and reduction rate of crude oil production. Previous researches findings have explored the variety application of WCO as the complete replacement, partial replacement, or modifiers for neat asphalt binder [4].

2.0 WASTE COOKING OIL

In general, the dumping activity of untreated waste cooking oil into the landfill or river cause the negative effect towards an environmental aspect. One of the major environment issue arise is eutrophication process which happen when there is an obstacle for sunlight to penetrate on the surface of river caused by the blocking from the thin layer of oil. Eventually, oxygen supply for aquatic life is disturbed when eutrophication take place in river [5-6]. Imbalance equilibrium of aquatic ecosystem in lake or river has affected the water quality as well. Engine oil from vehicles or waste cooking oil from residential areas contributes the major source of river pollution. The responsibility to overcome the high construction cost and minimize the waste dumping issues has initiated the recycling practice of waste oil as an option and alternative method in preventing these problems [5].

According to Hamad *et al.* [6] and Singhabhandhu and Tezuka [7], only the authorized companies appointed which responsible to collect Waste Cooking Oil (WCO) from food industries especially fastfood restaurant before sending to recycling centers. Zhang *et al.* [8] has explained the production of waste cooking oil originating from the frying activity at high temperatures during preparation of food which are usually performed in food industries, restaurants, hotels and residences. The unused of waste cooking oil are usually untreated with the appropriate treatment and discharged into the river illegally. Statistic from the EPA [9], the collection of waste cooking oil from food restaurant is recorded approximately 3 billion gallons annually. The application of WCOs are variety for example used as yellow grease [10], potential as fuel source in producing bio diesel [11], animal foods [12], and make soaps production [13]. Eventhough an effort to strive hard in collecting until 15 million tons of WCO annually [13], only a little quantity of waste cooking oil is managed in a right way by recycling process [12]. Monitoring and systematic management of WCO create challenge to be faced and become main consideration to overcome serious dumping problems that eventually create serious water pollution [13]. The total production of WCO by the countries is shown in Figure 1. The production of 10 million tonnes of WCO per year which is represent for 55% makes the United States known as the top producer of WCO. Meanwhile, the lowest production of WCO is recorded by Ireland which indicates only 1% for about 153,000 tons per year. Only 3% of waste cooking oil is produced in Malaysia based on the statistic. In Malaysia, oil based palm is selected as major source for cooking oil production due to its cheap processing cost and abundance of palm oil source from palm plantation in this country.

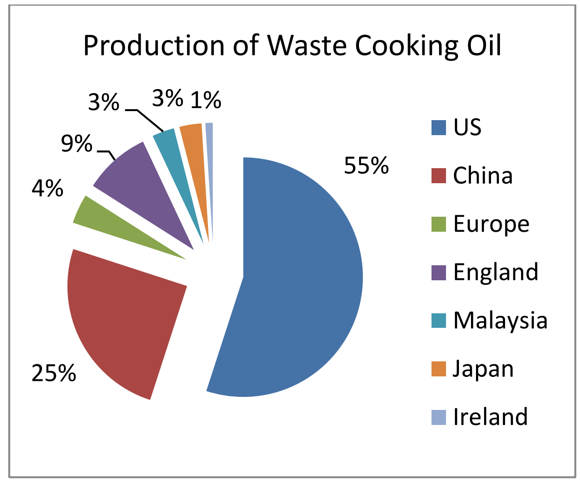


Figure 1 Waste cooking oil production based on country [10,14-15]

The large quantity of vegetable oil consumption about 17 million tons cause enormous quantity of waste frying oil resources production and this amount increasing approximately 2% each passing year [16]. Clogging problem is one of the critical problems when dealing with waste frying oils and eventually can pollute the water resources. Therefore, high processing costs is required to treat the polluted waste water [17]. Based on the Agricultural and food development authority report [16], 40% of sewerage system is blocked with waste frying oil which is throwing into the kitchen sink.

2.1 Chemical Properties

Gas chromatography mass spectrometry test (GCMS) is one of the chemical test that is used for the purpose of the identification of chemical compound in unknown waste cooking oil. Based on the observation, the major chemical compound identified in the WCO is oleic acid which is represents for 43.67% from the entire compound. Meanwhile, palmitic acid represents for 38.35% whereas 11.39% is recorded for linoleic acid as shown in Table 1. Due to long chain of palmitic acid and oleic acid [18], the potential of being cracked is high by thermal cracking or catalytic cracking process. Based on the research conducted by Zahoor *et al.* [19], the properties of unused oil is differ from used cooking oil especially in term of density, kinematic viscosity and moisture content which presented in Table 2.

Table 1 Chemical properties of waste cooking oil [18]

Type of Free Fatty Acid	% Waste Cooking Oil
Oleic acid	43.67
Palmitic acid	38.35
Linoleic acid	11.39
Stearic acid	4.33
Myristic acid	1.03
γ- Linolenic acid	0.37
Lauric acid	0.34
Linolenic acid	0.29
Cis-11-Eicosenoic acid	0.16
Heneicosanoic acid	0.08
TOTAL	100

Table 2 Physiochemical properties of used and unused cooking oil [19]

Properties	Unused Cooking Oil Values	Used Cooking oil Values
Acid value (mg KOH/gm)	0.3	4.03
Calorific value (J/gm)	-----	39658
Saponification value (mg.KOH/gm)	194	177.97
Peroxide value (meq/kg)	< 10	10
Density (gm/cm^3)	0.898	0.9013
Kinematic Viscosity (mm^2/s)	39.994	44.956
Dynamic Viscosity (mpa.s)	35.920	40.519
Flash point (°C)	161-164	222-224
Moisture content (wt. %)	0.101	0.140

3.0 PROCESS INVOLVED IN FRYING ACTIVITY

In frying activity, the heating process at temperatures ranging from 160-200°C of oil (lipids) is done for certain time. Mostly similar oil/fat is repeatedly used for economic purposes [20]. During frying process, oil is heated with high temperature in the presence of air and moisture. There is several degradation processes involve during frying activity listed below:

i. The production of free fatty acids (FFA), mono, and diglycerides from the hydrolysis of moisture content in fried food;
ii. The oxidation process that occurred because of the contact with oxygen. Due to oxidation process, the oxidized oligomeric triglycerides, dimeric, momomeric, and volatile materials such as aldehydes and ketones are produced from this reaction;
iii. A ring structure of dimeric and polymeric triglycerides is produced from polymerization caused by these two reactions, and high temperatures [21-23].

Evidently, the changes in waste oil composition after frying process can be identified by physical and chemical aspect. There are several physical altered in WCO which are (i) high viscosity, (ii) higher specific heat, (iii) change of surface tension, (iv) color exchange and (v) maximize tendency rate of fat to convert into foam. Nawar [24] and Mittelbach and Enzelsberger [25] stated that there are three reactions are involved during frying which are: thermolytic, oxidative, and hydrolytic.

- Thermolytic Reactions. A reaction that happens at very high temperatures without oxygen supply. A series of lower fatty acids, oxopropyl esters, symmetric ketones, normal alkanes, alkenes, CO, and CO_2 is produced when the triglycerides that comprise saturated fatty acids are heated at very high temperature (180°C) in the absence of oxygen.
- Oxidative Reactions. Free-radical mechanism is occurs when molecular oxygen has reacted with unsaturated fatty acids. This mechanism has produced a primary product known as Hydroperoxides which may continue form other compounds of conjugated diene groups which is contained in isomeric hydroperoxides.
- Hydrolytic Reactions. A reaction which triglycerides are hydrolysed by the steam produced during the food preparation, resulting in the formation of diglycerides, monoglycerides glycerol and free fatty acid (FFA) [25]. Hydrolytic reaction can alter the oil composition and can be measured by diglyceride and monoglyceride content instead of FFA content in oil due to the loss of FFA during frying process [26].

4.0 BINDER PERFORMANCE

Typically, modified asphalt binder is produced when the oily form of waste cooking oil is mixed together with neat binder. According to Asli *et al.* [27] and Bailey and Philips [28], WCO can also be directly poured into the heated aggregate and apply as a rejuvenator in Reclaimed Asphalt Pavement (RAP). The properties of binder will be changed when the WCO is added into the mixture. Binder evaluation can be performed by conducting dynamic shear rheometer test, viscosity, softening point test and penetration test to identify different properties of binder. Table 3 and Table 4 show the performance of binder containing waste cooking oil which is conducted by the previous study.

Based on the findings from Bailey and Philips [28], when the amount of oil added into the mixture and the temperature is increased, it will affect the reduction of the viscosity of the samples. The value of viscosity in the mixtures without addition of oil at 180°C, 150°C, and 120°C are 0.074 Pa.s, 0.231 Pa.s, and 1.074 Pa.s is presented in Table 4. Meanwhile, the addition of 10% of oil content in the mixture shows the different viscosity result of 0.044 Pa.s, 0.117 Pa.s, and 0.429 Pa.s at temperature 180°C, 150°C, and 120°C which is lower than neat bitumen. Besides, the high penetration value is achieved with the increasing amount of WCO due to low viscosity property. The addition of WCO at certain grade of bitumen has resulted the similar penetration value as neat binder [5,36] and the potential as a rejuvenator has increased the fatigue resistance of the mixture [29]. Research conducted by Zargar *et al.* [30] has concluded that 4% of WCO which is added into 40/50 grade of aged bitumen achieved the same viscosity results as the neat bitumen.

Table 3 Binder evaluation based on previous study

Researcher	Summary of findings
Bailey and Philips [28]	About 9-11% waste vegetable oil was recognized to rejuvenate aged samples from field to the targeted 40/60 penetration grade binder. They found that increasing of oil content and temperature has decreased the viscosity of the samples shown in Table 4.
Asli and Karim [31]	The penetration value increase when the amount of WCO increased. About 3.6% and 2.7% of WCO added to grade of 30/40 and 40/50 has resulted the same penetration value with the neat bitumen.
Zaumanis *et al.* [29]	At 12% dose from binder weight, WCO showed the most rejuvenator potential by increasing fatigue resistance.
Zargar *et al.* [30]	Almost the same viscosity as the neat bitumen is achieved when 4% of WCO is added into the aged binder from the 40/50 grade.
Asli *et al.* [27]	The aged binder of bitumen group 50/60 needed 1%, group 40/50 needed 3- 4% and group 30/40 needed 4 – 5% as the optimum WCO to achieve the original penetration value 80/100.

Table 4 Viscosity value based on different temperature [28]

Oil Content (%)	Viscosity (Pa.s)		
	120°C	150°C	180°C
0	**1.074**	**0.231**	**0.074**
2	0.844	0.200	0.064
4	0.723	0.172	0.060
6	0.607	0.151	0.053
8	0.504	0.131	0.046
10	0.429	0.117	0.044

5.0 ASPHALT MIXTURES PERFORMANCE

Basically, mixture performance is evaluated from significant properties of bituminous pavement which are stiffness, rutting resistance and cracking resistance [32]. The viscosity is reduced with the addition of oil in the binder which eventually can soften oil-binder mixture. Therefore, rutting problem start to occur due to soft condition in asphalt binder contains oil in the mixture. Therefore, permanent deformation was observed when higher rutting potential [33]. Permanent deformation of asphalt mixture is assessed by conducting creep test. Borhan et al. [34] reported that the increasing amount of used cylinder oil has indicated the reduction rate of creep stiffness due to the weak bonding between the binder and aggregate in the mixture. Bailey and Philips [28] reported that the stiffness of the aging mixture can be reduced by the application of used vegetable oil. Reasearch done by Zaumanis *et al.* [35] revealed that the fatigue resistance can be significantly increased by the addition of waste vegetable oil and similar number of cycles failure is achieved as control mix. In addition, Zargar *et al.* [30] has concluded that the rate tendency of rejuvenated bitumen to aging is minimized compared to neat bitumen with the reduction of asphaltenes index value as shown in Table 5.

Table 5 Ageing of rejuvenated bitumen [30]

Test Properties	Aged of Bitumen	Rejuvenated of Bitumen
Viscosity (mPa.s)	400	432.4
Viscosity Ageing Index (%)	1.31	1.03
Penetration (0.1mm)	60.0	67.0
Softening Point (°C)	48.3	48.0
Loss in Penetration	25.0	14.0
Complex Shear Modulus (64°C)	357.25	292.5
Complex Shear Modulus Changes	1.56	1.08
Asphaltenes Index	1.03	1.018
Asphalt Volatility	-0.275	-0.174

6.0 CONCLUSION

As a conclusion, the application of waste cooking oil (WCO) generally has contributed for positive impact to the pavement performance directly or indirectly which has emphasized in this paper. The addition of WCO as a rejuvenator to the aged binder is recorded by enormous of previous research. Bio-asphalt production from the addition of WCO has indicated the high potential of WCO as a replacement of the conventional asphalt binder which eventually contributes to the minimization of environmental degradation problem. Binder modification by applying the WCO has indicated the penetration, softening point and viscosity value changes for binder evaluation. The research scope should be extended to discover more the other usage of WCO in binder for future research.

Acknowledgement

The support provided by Malaysian Ministry of Higher Education (MOHE) and Universiti Teknologi Malaysia (UTM) in the form of a research grant number Q.J130000.2522.09H67 and Q.J130000.2422.02G91for this study is very much appreciated.

References

[1] Williams, R. C., Satrio, J., Rover, M., Brown, C. R., and Teng, S. 2009.Utilization of Fractionated Bio Oil In Asphalt. *Transportation Research Board 88th Annual Meeting*, Transportation Research Board, Washington, DC.

[2] Fini, H. E., 2011. Chemical Characterization Of Bio-Binder From Swine Manure: Sustainable Modifier For Asphalt Binder. *Journal of Material in Civil Engineering*. 23: 1506–1513.

[3] You, Z., Beale, J. M., Fini, H. E., Goh, S. W. and Colbert, B. 2011. Evaluation of Low Temperature Binder Properties Of Warm Mix Asphalt, Extracted And Recovery RAP and RAS, and Bioasphalt. *Journal of Material in Civil Engineering*. 23: 1569–1574.

[4] Raouf, M. A. and Williams R. C. 2010. Temperature Sussceptibility of Non-petroleum Binders Derived from Bio-oils. Paper presented at *The 7th Asia Pasific Conference on Transportation and the Environment*, Semarang, Indonesia.

[5] El-Fadel, M., and Khoury, R. 2001. Strategies for vehicle waste-oil management: a case Study. *Resources, Conservation and Recycling*, 33: 75–91.

[6] Hamad, B. S., Rteil, A. A. and El-fadel, M. 2003. Effect of Used Engine Oil On Properties Of Fresh And Hardened Concrete. *Construction and Building Materials*. 17: 311–318.

[7] Singhabhandhu, A. and Tezuka, T. 2010. The Waste-To-Energy Framework For Integrated Multi-Waste Utilization: Waste Cooking Oil, Waste Lubricating Oil, And Waste Plastics. *Energy*. 35(6): 2544–2551.

[8] Zhang, H.,Wang, Q. and Mortimer, S. R. 2012. Waste Cooking Oil As An Energy Resource: Review of Chinese Policies. *Renewable & Sustainble Energy Reviews.* 16(7): 5225–5231

[9] EPA.2011.(http://www.epa.gov/region9/waste/biodiesel/questions.html) (Aug. 2011).

[10] Gui, M. M., Lee K. T. and Bhatia, S. 2008. Feasibility of Edible Oil vs. Non-Edible Oil vs. Waste Edible Oil as Biodiesel Feedstock. *Energy.* 33(11) (2008): 1646–1653.

[11] Peiro, L. T., Lombardi, L., Méndez, G. V. and Durany, X. G. 2010. Life Cycle Assessment (LCA) and Exergetic Life Cycle Assessment (ELCA) of the Production Of Biodiesel From Used Cooking Oil (UCO). *Energy.* 35(2): 889–893.

[12] Castellanelli, C. A. 2007. *Analyzes of the Used Oil Under Environmental Perspective And Its Possibilities For Production Of Biodiesel.* Courtesy of UFSM – Federal University of Santa Maria.

[13] Math, M. C., Kumar, S. P. and Chetty, S. V. 2010. Technologies for Biodiesel Production From Used Cooking Oil – A Review. *Energy for Sustainable Development*. 14 (4): 339–345.

[14] Kulkarni, M. G., and Dalai, A. K. 2006. Waste Cooking Oil - An Economical Source for Biodiesel: A Review. *Industrial & Engineering Chemistry Research*. 45(9): 2901–2913.

[15] Moghaddam, T. B., Karim, M. R. and Abdelaziz, M. 2011. A Review On Fatigue And Rutting Performance Of Asphalt Mixes. *Scientific Research and Essays*. 6(4): 670–682.

[16] Agriculture and Food Development Authority, Waste Oils and Fats as Biodiesel Feedstocks. 2000. *An Assessment of Their Potential in the EU,* ALTENER Program NTB-NETT Phase IV, Task 4, Final Report, March 2000.

[17] Sanli, H., Canakci, M. and Alptekin, E. 2011. Characterization of Waste Frying Oil Obtained From Different Facilities. *World Renewable Energy Congress* 2011- Sweden 8-13 May 2011, Linkoping, Sweden.

[18] Khalisanni, K., Khalizani, K. Rohani, M.S., and Khalid, P.O. 2008. Analysis of Waste Cooking Oil As Raw Material For Biofuel Production. *Global Journal of Environmental Research*. 2(2): 81-83.

[19] Zahoor, U., Mohamad A. B., and Zakaria M. 2014. Characterization of Waste Palm Cooking Oil for Biodiesel Production. *International Journal of Chemical Engineering and Applications.* 5(2): 134-137

[20] Cvengros, J. and Cvengrosova, Z. 2004. Used Frying Oils and Fats and their Utilization in the Production of Methyl Esters of Higher Fatty Acids. *Biomass Bioenergy* 2004, 27: 173-181.

[21] Gertz, C. 2000. Chemical and Physical Parameters as Quality Indicators of Used Frying Fats, Euro Lipid. *Science Technology* 102: 566-572.

[22] Stevenson, S.G., Vaisey-Genser M. and Eskin N.A.M. 1984. Quality Control in the Use of Deep Frying Oils. JAOCS. 61: 1102-1108.

[23] Choe, E. and Min, D.B. 2007. Chemistry of Deep-Fat Frying Oil. *Journal of Food Science*. 72: 78-86

[24] Nawar, W. W. 1984. Chemical Changes in Lipids Produced by Thermal Processing. *Journal of Chemical Education*. 61(4): 299-302.

[25] Mittelbach, M. and Enzelsberger, H. 1999. Transesterification of Heated Rapeseed Oil for Extending Diesel Fuel. *Journal of the American Oil Chemists' Society*. 176(5): 545-550.

[26] Guesta, F. J., Sanchez-Muniz, C., Polonio-Garrido, S., Varela-Lopez, and Arroyo, R. 1993. Thermoxidative and Hydrolytic Changes in Sunflower Oil Used in Frying with a Fast Turnover of Fresh Oil. *Journal of the American Oil Chemists' Society*. 70(11): 1069-1073.

[27] Asli H., Ahmadinia E., Zargar M., and Karim M. R. 2012. Investigation on Physical Properties Of Waste Cooking Oil – Rejuvenated Bitumen Binder. *Construction Building Material* 37: 398–405.

[28] Bailey, H. K. and Philips, P. 2010. *Asphalt Rejuvenation. US Patent.* 0034586 A1.

[29] Zamhari, K. A., Yunus K. N. M., Hermadi, M. and Adan, A. A. 2011. *A Study On The Technical Viability Of Utilizing Used Lubricating Oil As Rejuvenating Agent In Reclaimed Asphalt And Pavement.*1-25

[30] Zargar, M., Ahmadinia E., Asli, H. and Karim, M. R. 2012. Investigation of the Possibility Of Using Waste Cooking Oil As A Rejuvenating Agent For Aged Bitumen. *Journal of Hazardous Materials*. 233–234 : 254–258

[31] Asli, H. and Karim, M. R. 2011. Implementation of Waste Cooking Oil as RAP Rejuvenator. *Journal of the Eastern Asia Society for Transportation Studies*. 9.

[32] Widyatmoko, I. 2008. Mechanistic-Empirical Mixture Design For Hot Mix Asphalt Pavement Recycling. *Construction Building Material*. 22(2): 77–87.

[33] Borhan, M. N., Suja, F., Ismail, A. and Rahmat, R. A. 2009. The Effects of Used Cylinder Oil on Asphalt Mixes. *European Journal of Scientific Research*. 28(3): 398–411.

[34] Borhan, M. N., Suja, F., Ismail, A. and Rahmat, R. A. 2007. Used Cylinder Oil Modified Cold-Mix Asphalt Concrete. *Journal of Applied Sciences*. 7(22): 3485–3491.

[35] Zaumanis, M., Mallick, R. B. and Frank, R. 2013. Use of Rejuvenators for Production of Sustainable High Content RAP Hot Mix Asphalt. *28th International Baltic Road Conference*, Vilnius, Lithuania.