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Thermal Behavior of Asphalt Pavement as an Active Solar Collector under Malaysia Climate Condition Using Rubber Tube

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Abstract: Malaysia has potential to generate alternative renewable solar energy. Rubber tube was embedded in asphalt pavement at a depth of 75 mm. Thermal behavior of solar heat was studied at different location in asphalt pavement. Asphalt pavement top surface which is exposed to the direct sunlight, temperature above the rubber tube, temperature of liquid (water) filled in rubber tube and temperature below the rubber tube were the locations chosen to observe the thermal behavior and heat transformation from top to bottom. The observation was carried out for 3 days in asphalt pavement and using thermodynamic first law to find the heat efficiency. Study concludes that the maximum surface temperature reach to 59.5°C and water inside rubber tube temperature reach to 54.7°C. In the result minimum 2.4% and maximum heat efficiency 22.7% produced by using rubber tube the case might be change using other metals.

Key words: Thermal behavior, asphalt pavement, solar collector, rubber tube, temperature, bottom

INTRODUCTION

The geographical existence and metrological data study of Malaysia is important to comprehensively understand thermal behaviour of asphalt pavement incorporation with solar irradiation. In the context of Malaysia, the country is tropical and daylight temperature range from 21-35°C. The relative humidity of Malaysia ranges from 80-88%, nearly 90.0% in highland area and lowest recorded humidity is 60%. The highest solar radiation of 6.8 kWh/m^2 was recorded in the month of August and November while the lowest solar radiation of 0.61 kWh/m^2 was recorded in the month of December. However, yearly an average daily solar irradiations for Malaysia were from 4.21-5.56 kWh/m^2 (Engel-Cox *et al*., 2012; Azhari *et al*., 2008; Kadirgama *et al*., 2014). Malaysia has potential to utilize solar energy as an alternative energy resource, since, abundant sunshine received annually (Azhari *et al*., 2008). Heat conductivity property of asphaltic materials leads the pavement surface heat up to 70°C in summer by direct solar radiation (Munoz *et al*., 2013; Wu *et al*., 2007). High temperature badly effect the quality of bitumen surface in the result safety concern raised like rutting and heat island (Berdahl *et al*., 2008). Thermal conductivity property of asphalt material might increase the possibility of supply thermal energy by collecting heats through solar collectors from the parking lots and roadways adjacent to the buildings (Munoz *et al*., 2013). High temperature in asphalt pavement leads the environment to the global warming. The implementation of natural resource of energy is more favorable due to its availability, environmental friendly and cost effective. Solar energy is available and relatively cheap to be harvested and utilize, especially in hot weather countries (Munoz *et al*., 2013; Wu *et al*., 2007). Fossil fuels reserves are limited and on the depletion of natural energy resources scientist's opinions varied (Hook and Tang, 2013). The energy produce with fossil fuel found one of the core reasons for environmental pollution. Problems with the generation of fossil fuel energy are not only effect global warming also an create an environmental issues such as air pollution, acid raining, depletion of ozone, deforestation and the emission of radioactive substances would affect human life on the earth.

Various aspects of asphalt and heat have been studied where asphalt structure cracking, healing, thermal behaviour, asphalt latent heat storage and source of heat island are the effect of heat (Xu and Solaimanian, 2010; Martinkauppi *et al*., 2015). Researchers are motivated to

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find alternative clean, green and renewable energy for the clean and green environment. The collection and utilization of solar energy from the direct sun lights using solar panels became an old fashion while the collection of solar energy from the roadways/asphalt pavement are becoming popular and open new ear for the researchers. Asphalt energy harvesting is new approach towards green renewable energy. The accumulation of available energy reservoir in densely populated towns where major portion is asphalted. The asphalt has potential to collect heat energy (Munoz *et al*., 2013). The aim of the study is to investigate heat transformation in asphalt pavement using rubber tubes as a solar collector also to determine harvested energy efficiency from the liquid extraction of rubber tubes.

Literature review

Heat transfer phenomena in asphalt pavement: Heat is the energy transferred from one body or system to another as a result of a change in temperature. The flow of heat transferred always traced from hot object to the cold object. The heat transferred by three means which are conduction, convection and radiation (Sullivan *et al*., 2008). Heat transfer by the emission of electromagnetic waves which carries energy away from the emitting object is called radiation. The radiation heat transfer does not require the presence of an intervening medium, occurs at the speed of light and suffers no attenuation in a vacuum. These conditions allow a fraction of the thermal energy generated by the sun to be transferred to the pavement surface (Sullivan *et al*., 2008). The asphalt pavement which is exposed to the solar radiation the heat exchanged happened at the surface of the pavement. The radiation emitted by the interior regions of the pavement can never reach the surface while the radiation incident on the pavement is absorbed within a few microns from the surface (Munoz *et al*., 2013; Wu *et al*., 2009; Berdahl *et al*., 2008; Hook and Tang, 2013; Sullivan *et al*., 2008; Cengel and Ghajar, 2010). The heat transferred model in asphalt pavement is shown in Fig. 1.

Thermal behavior of flexible/asphalt pavement and energy harvesting: The thermal properties of Asphalt Concrete (AC) materials such as the thermal conductivity, diffusivity and heat capacity have been studied. The thermal behavior of the asphalt pavement is depended on the geometry and size of the asphalt concrete material (Xu and Sulaimanain, 2010). The mechanical behavior of Asphalt Concrete (AC) is highly temperature dependent. Asphalt Concrete (AC) expands with increasing temperature and contracts with decreasing temperature, results in thermal cracking

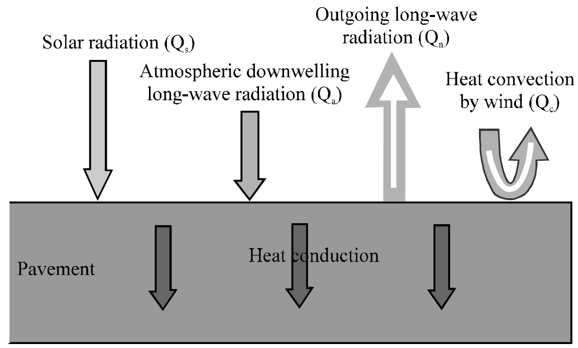

Fig. 1: Schematic presentation of heat transfer model of pavement (Sullivan *et al*., 2008)

(Martinkauppi *et al*., 2015; Xu and Solaimanian, 2008, 2010). In the meantime, on high temperature the asphalt become soft and subjected to rutting under repeated traffic load. On other side when the temperature is low asphalt become hard and subjected to thermal cracking or brittle. Based on asphalt related facts, research studies have been conducted to measure in situ pavement temperature topredict the thermal behavior of asphalt pavement at various temperatures (Xu and Mohammad, 2008; Christison and Anderson, 1972). Particles size, geometry and distribution in asphalt concrete have significant relationship with time and thermal temperature of asphalt concrete (Xu and Mohammad, 2008). Laboratory study on solar collector of thermal conductive asphalt concrete has been conducted and the findings shows that the heat energy obtained from solar irradiation can be enhanced by means of conductive asphalt concrete (Wu *et al*., 2009). A multi-layered asphalt pavement is designed in the laboratory where the middle layer is highly porous up to 27.0% voids which freely allow the water to circulate and collected energy in pavement is harvested (Minoz *et al*., 2013). Previously Wu *et al*. (2009), Dehdezi (2012) and Mingyu *et al*. (2010) have conducted serious of studies using copper, iron and stainless pipes to measure heat energy in asphalt pavement at various depths. The results showed the use of aggregates with high values of conductivity can enhance the solar heat collection efficiency and that the depth of the copper pipes frame is critical. Wu *et al*. (2009) and Mallick *et al*. (2010) concluded that the heat transfer from the top to the bottom of asphalt slabs becomes faster when graphite powder is added. Mingyu *et al*. (2010) further concluded that by addition of graphite powder to the asphalt pavement will enhance solar heat harvesting efficiency. Lack of studies conducted using rubber tubes for harvesting heat energy in asphalt pavement and this study majorly focused on rubber tubes embedded in asphalt pavement.

Benefits of energy harvesting from asphalt pavement: The concept of energy harvesting is using a piping network embedded below the surface of asphalt pavements filled with appropriate fluid allow thermal energy to flow in the result following advantages outlined (Winterbone and Turan, 1996; Wu *et al*., 2009; Mallick *et al*., 2009; Dehdezi, 2012). To reduce the temperature of the asphalt pavement reduce urban heat island effect, use the heated fluid for different end applications such as heating, power generation or refrigeration. The reduced temperature will extend the life of the pavement while the reduced temperature of the near surface air will lead to savings in energy consumption of adjacent buildings and improvement in air quality (such as by reducing ozone concentration). The concept of using fluid in pipes: to harvest energy from asphalt pavements, reduce the temperature of the pavement, to reduce the amount of heat that is radiated back from the pavement surface to the atmosphere (urban heat island effect); reduce the high temperature related permanent deformation potential of the pavement.

Fig. 2: Asphalt placement rubber tube embedded

MATERIALS AND METHODS

Material and test specimens preparation: Plywood box of 300×300×150 mm size filled with asphalt pavement. The rubber tube of 25 mm diameter was embedded at depth of 75 mm. The embedded rubber tube is filled with tape water. The temperature was measured with the help of digital data logger and the data logger was connected with serious of thermocouple. Infrared thermometer was used to measure the temperature of asphalt pavement on surface and below surface. Figure 2 indicated the rubber tube placement and thermocouple connection with surface with inside connection to help in the measurement of temperature. Surface temperature was measured with infrared thermometer. Thermocouple is placed above and below the rubber tube embedded in asphalt concrete to help in recording the temperature in desired place; thermocouple is connected with digital data logger.

(a)

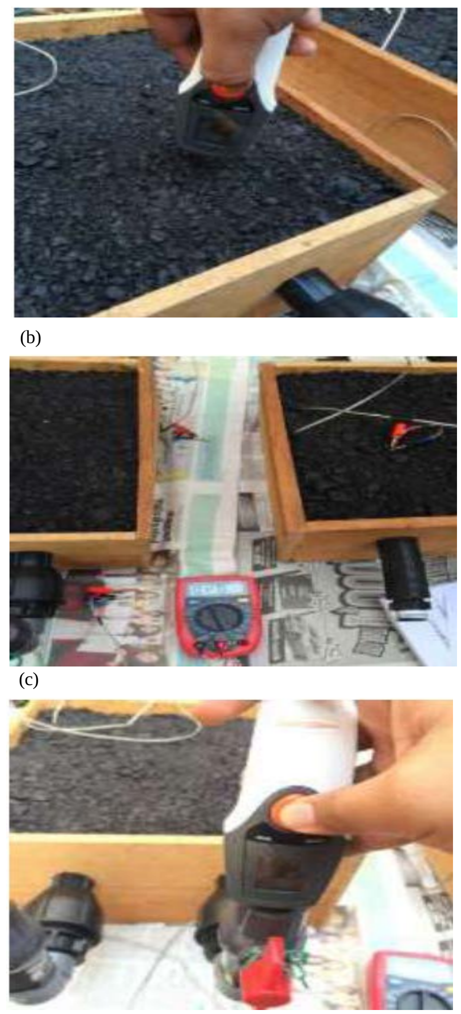

Fig. 3: Temperature measurement at different locations (T1-4)

Temperature measurement: The prototype was placed under direct sun light and was monitor from 7 am till 7 pm. Temperature on the asphalt surface layer, temperature at above and below the rubber tube and temperature of water was measured. Figure 3 shows the temperature measurement on asphalt surface (T1); temperature above rubber tube (T2); below rubber tube (T4) and temperature of water (T3) and Fig. 4 shows prototype illustration. The heat efficiency is calculated by using Eq. 1 Munoz *et al*., 2013):

$$\text{Heat efficiency } (\eta) = \frac{\text{Surface Temperature (T1)-Inner Temperature of tube (T3)}\times 100\%}{\text{Surface Temperature (T1)}}$$

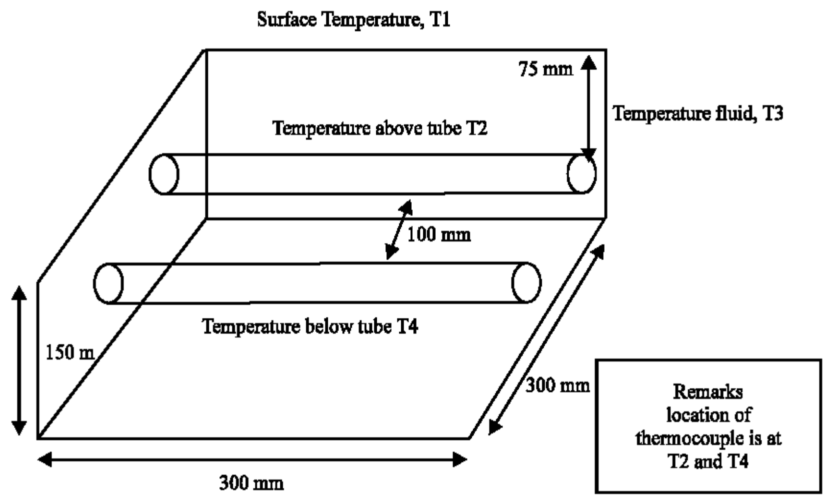

Fig. 4: Prototype illustration

Table 1: Day 1-3 thermal behavior of asphalt pavement at various locations

	Surface temperature (T1)°C			Temperature below tube (T4)°C			Temperature above tube (T2)°C			Water Temperature (T3)°C		
Hours	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
Initial (7 am)	29.9	30.1	28.9	28.0	30.0	30.0	30.0	29.0	27.0	26.9	28.7	28.2
7 to 8 am	31.1	30.9	29.1	28.0	30.0	29.0	31.0	31.0	28.0	27.8	30.0	28.5
8 to 9 am	34.3	33.8	32.4	29.0	30.0	30.0	32.0	31.0	28.0	31.3	32.5	29.1
9 to 10 am	36.9	36.7	35.4	32.0	31.0	31.0	33.0	32.0	30.0	33.9	34.7	33.5
10 to 11 am	39.9	38.9	42.3	33.0	32.0	33.0	34.0	34.0	31.0	35.4	37.6	36.1
11 am to 12 pm	45.7	46.8	45.2	35.0	34.0	34.0	36.0	36.0	32.0	38.1	43.1	41.9
12 to 01 pm	59.2	59.5	58.0	38.0	39.0	35.0	41.0	41.0	32.0	51.0	54.7	50.9
1 to 0 2 pm	54.6	58.1	55.6	41.0	40.0	37.0	44.0	42.0	33.0	47.7	52.9	48.7
2 to 03 pm	50.7	55.9	51.0	45.0	43.0	38.0	47.0	41.0	35.0	42.5	48.9	43.9
3 to 4 pm	44.1	51.4	47.2	39.0	41.0	36.0	42.0	41.0	36.0	39.9	44.1	38.7
4 to 5 pm	40.8	46.3	44.5	38.0	41.0	35.0	40.0	40.0	34.0	36.5	39.3	34.4
5 to 6 pm	36.7	40.9	39.5	37.0	39.0	35.0	38.0	38.0	33.0	33.2	37.3	31.2
6 to 7 pm	33.6	37.1	34.1	36.0	37.0	35.0	37.0	36.0	33.0	30.9	34.0	29.9

RESULTS AND DISCUSSION

Thermal behavior: The experiment was carried out for 3 days started from 14th August 07 am to 07 pm under direct sunlight, since, study is depended on solar heat and whether condition plays an important role in this study. Rubber tube is filled with tape water and obtained result of day 1-3 is shown in Table 1. The findings indicated that the maximum surface temperature T1 was recorded at hours of 12-01 pm at day 1, 59.2°C; day 2, 59.5°C and day 3, 58.0°C. The temperature varies hour to hour's morning 7 am minim um T1 temperature has been recorded for 3 days. Since, temperature transformation occurred from top surface to the lower part of the asphalt pavement, T4 represent temperature below embedded rubber tube. This is evidently shows the temperature transformation occurred in the asphalt pavement. The maximum temperature T4 was recorded in interval of between 2-3 pm as day 1, 45.0°C, day 2, 43.0°C and day 3, 38.0°C, accordingly. The experiment further find the temperature just above the rubber tube embedded in asphalt pavement showing temperature T2, the day one maximum T2 was recorded 2-3 pm interval of 47.0°C, day 2, 1-2 pm 42.0°C and day 3, 3-4 pm 36.0°C. Rubber tube was filled with tape water temperature T3 represent water temperature the maximum T3 at interval of 12-01 pm 51.0°C day 1, day 2, 54.7°C at 12-01 pm and day 3, 50.9°C at 12 -01 pm. The thermal behavior data obtained of three days experiments indicated that solar heat collected on the pavement surface and heat traveling from top surface to lower surface also through embedded rubber tube with filled water shows higher temperature absorbed at peak solar hours. At the same phase due to weather change or raining temperature drop within asphalt body has seen as shown in Table 1. Figure 5 shows graphically representations between surface temperature T1 and fluid temperature inside the rubber tube T3, the trend indicated the heat travelled from the surface and water temperature

Table 2: Thermal efficiency of solar asphalt pavement

Hours	Surface temperature (T1)			Water temperature (T3)			Heat efficiency (η) (%)		
	D1	D2	D3	D1	D2	D3	D1	D2	D3
Initial (7 am)	29.9	30.1	28.9	26.9	28.7	28.2	10.0	4.7	2.4
7 to 8 am	31.1	30.9	29.1	27.8	30.0	28.5	10.6	2.9	2.1
8 to 9 am	34.3	33.8	32.4	31.3	32.5	29.1	8.8	3.9	10.2
9 to 10 am	36.9	36.7	35.4	33.9	34.7	33.5	8.1	5.5	5.4
10 to 11 am	39.9	38.9	42.3	35.4	37.6	36.1	11.3	3.3	14.7
11 am 12 pm	45.7	46.8	45.2	38.1	43.1	41.9	16.6	7.9	7.3
12 to 01 pm	59.2	59.5	58.0	51.0	54.7	50.9	13.9	8.1	12.2
1 to 02 pm	54.6	58.1	55.6	47.7	52.9	48.7	12.6	9.0	12.4
2 to 03 pm	50.7	55.9	51.0	42.5	48.9	43.9	16.2	12.5	13.9
3 to 4 pm	44.1	51.4	47.2	39.9	44.1	38.7	9.5	14.2	18.0
4 to 5 pm	40.8	46.3	44.5	36.5	39.3	34.4	10.5	15.1	22.7
5 to 6 pm	36.7	40.9	39.5	33.2	37.3	31.2	9.5	8.8	21.0
6 to 7 pm	33.6	37.1	34.1	30.9	34.0	29.9	8.0	8.4	12.3

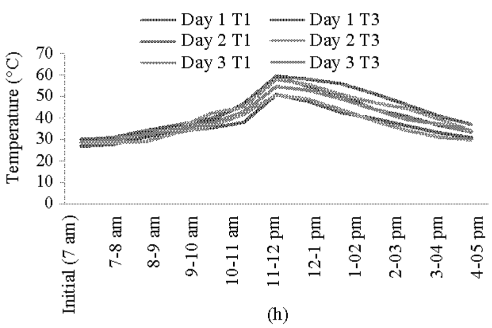

Fig. 5: Relation between surface Temperature (T1) and Fluid Temperature (T3)

inside the pipe significantly increased which further shows water has stored the heat energy. The peak hours 11 am to 3 pm shows higher temperature on the surface as well liquid temperature. Table 1, day 1-3 thermal behavior of asphalt pavement at various locations hours surface temperature.

Thermal efficiency: According to the first law of thermodynamics energy output cannot be exceed than energy input nor can it be equal, so when expressed in the percentage the efficiency must be between 0 and 100%. In the study, T1 is the surface temperature of asphalt pavement directly received from solar light under the heat transfer phenomena heat transfer from the top surface to the lower where rubber tube is embedded filled with water. The study findings is witnessed the temperature T3 is increased as the surface temperature T1 increased. Heat/Thermal efficiency of the fluid inside the rubber tube is determined using the Eq. 1. The heat efficiency extracted from the liquid is calculated and assembled in Table 2. The highest heat efficiency of 22.7% was found on third day at 04-05 pm sudden drop of water temperature due to raining or weather changed has shown the highest impact on heat efficiency. Hourly heat efficiency generated is shown graphically in Fig. 6.

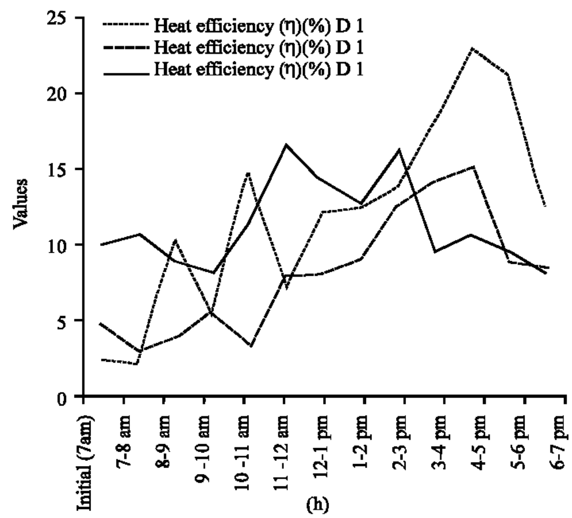

Fig. 6: Hourly heat efficiency (%)

CONCLUSION

The rubber tube filled with tape water was embedded in Asphalt Concrete (AC) at depth of 75 mm. The maximum average 58.9°C surface Temperature (T1) followed by below the rubber Tube (T4) maximum average 41.0°C; above the rubber tube (T2) maximum average 41.6°C and inside rubber tube liquid (water) temperature (T3) maximum average temperature 52.2°C was measured. The heat transformation shows that liquid inside rubber tube temperature increased as the surface temperature increase also T2 and T4 increased but due to void and air in asphalt pavement above and below rubber tube temperature is less than temperature store in water. The findings shows the water or liquid store received less energy comparatively surface but it produce high efficiency. Study concludes that the maximum fluid temperature inside rubber tube reaches to 54.7°C and highest heat efficiency is 22.7%. The heat efficiency depends on weather, asphalt tube materials.

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