Heat Lump in Different Pavement Layer Using Water as a Heat Collector

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Abstract: Asphalt pavements subject to solar radiation can reach high temperature causing not only environmental problems such as heat island effect on cities but also structural damage due to rutting or hardening of road. The main aim of this research is to determine the maximum heat area in pavement where the scope of study consists of field experiment under real atmospheric condition and laboratory testing. The rise in temperature of water solvent flowing through the conduction of steel pipe was used as indicator of the efficiency of heat capture. The data from field experiment had been collected using data logger and the reading of temperature was recorded every 5 min for 24 h starting from 12-12 am the next day for 3 days to get the average temperature reading of water solvent in steel pipes. Steel pipe with water solvent at depth of 50 mm has the maximum temperature of heat area in pavement with highest thermal storage and can withst and the highest vehicle loading applied on it.

Key words: Asphalt pavement, water solvent, steel pipe, pavement, temperature, environmental

INTRODUCTION

Solar energy is the primary energy source for all other forms of energy source distributed around the world. Road pavement is one of the largest solar thermal collector and storage system on land. It receives solar radiation all day and stores some of the energy from it. This energy is completely or partially dissipated to atmosphere by night time. An average temperature of an asphalt pavement can reach up to 60-70°C on hot day because of its excellent heat absorbing characteristic. The solar thermal energy collected by the asphalt pavement can be harvested by circulating fluid through it. A system that is designed for this purpose is called Asphalt Solar Collector (ASC).

Renewable energy technologies are likely to become more important as other energy sources become depleted and the cost of power generation using fossil fuels rises. However in most cases, renewable energy technologies require high initial investments that may deter potential users. Asphalt solar collector potentially offered a low-cost solution to sustainable and clean energy generation by using pavement infrastructure.

The water solvent in the pipes can absorb/reject heat to the pavement and store energy to in the pavement structure. A significant advantage of the system is that the pipes are installed within pavements that are already needed for structural reasons and need not to be specially constructed as the conventional thermal energy utilization systems such as solar panels. The ability of pavement to collect and/or store solar energy is a relatively new subject that is still at an early age of development. This research is in general to determine the maximum heat area in asphalt pavement by using steel pipe with water solvent.

Asphalt solar collectors consist of pipes embedded in the pavement with a circulating fluid inside. Solar radiation causes an increase in pavement temperature. Due to the temperature gradient between the fluid circulating through pipes and the pavement a heat transfer process occurs from pavement to fluid which leads to a drop in pavement temperature and an increase in fluid temperature (Jonathan, 2010).

This drop in asphalt temperature contributes to mitigate the heat island effect and reduce the risk of permanent deformations. However, what makes asphalt

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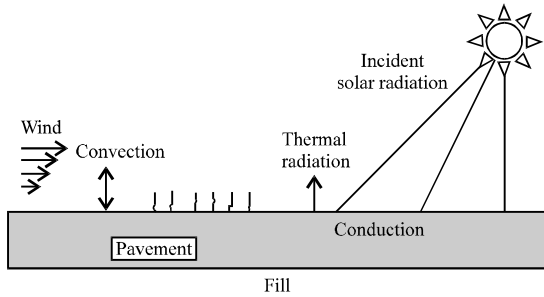
Fig. 1: Heat transfer modes in asphalt pavement

solar collectors really interesting is their ability to use the temperature rise undergone by the circulating fluid to harness energy. There are also concrete solar collectors but because of the black color, asphalt's solar absorption coefficient is higher than concrete (Larsson and Thelandersson, 2011). Thus, asphalt solar collectors perform better than the concrete pavement.

Literature review: Several researchers have developed methods to predict the asphalt temperatures because they will significantly affect the pavements where high temperatures can cause plastic deformations while lower temperatures can leads to damage by hardening.

The temperature distribution of an asphalt pavement is affected directly by the thermal environment conditions to which it is exposed. The primary modes of heat transfer include incident solar radiation, thermal and long wave radiation between the asphalt pavement surface and the sky, convection due to heat transfer between the pavement surface and the fluid (air or water) that is in contact with the surface, conduction inside the pavement and the radiation heat loss from surface. Figure 1 shows the various heat transfer modes in a heat conducting asphalt pavement exposed to solar radiation.

Asphalt solar collectors are usually coupled with low temperature geothermal heat pumps, obtaining reasonable efficiency and operating costs. Energy obtained from asphalt solar collectors is generally used for snow melting systems or to maintain thermal comfort of adjacent buildings (Larsson and Thelandersson, 2011). Due to the properties, asphalt pavement had been widely used in parking lots and roadways.

A numerical simulation was developed by Wang *et al.* (2010) in which a model of an asphalt collector with a net of rubber pipes in its middle layer was used to predict the thermal response of these devices in order to determine which parameters were critical in the behavior of an asphalt collector (Shaopeng *et al.*, 2011). Besides that, Shaopeng *et al.* (2011) had investigated the

process of extracting thermal energy from asphalt slabs with u-shaped metal tubes inside. It was proven that the circulating water can reduce the surface temperature of the asphalt pavement thus reducing the risk of permanent deformation and the urban heat island effect (Liu *et al.*, 2015).

Heat exchangers are normally used only for the transfer and useful elimination or recovery of heat without an accompanying phase change. The fluids on either side of the barrier are usually liquids but they may also be gases such as steam, air or hydrocarbon vapors or they may be liquid metals such as sodium or mercury. Fused salts are also used as heat-exchanger fluids in some applications. The exchangers are used to recover heat between two streams in a process; these fluids may be single compounds or mixtures (Hasnain, 2011).

The characteristics required for the circulating fluid are: high specific heat, stability in the collector operating temperature range, compatibility with pipes, abundance and low cost. Water is one of the best fluids for systems operating at low temperatures (range from 25-90°C) such as asphalt solar collectors but the solidification temperature must be less than the minimum temperature expected at the collector. For this reason, mixtures of water and antifreeze are generally used.

MATERIALS AND METHODS

Experiments began with the preparation of samples that was done according to the standard specifications of pavement before the collection and analysis of data. This chapter will describes the process throughout the research and necessary steps to be studied from the beginning of the research until the laboratory testing to analyze the expected results of the study.

After identifying the materials and apparatus needed, field experiment and laboratory testing will be conducted in Highway Laboratory in UTHM. The results obtained from the observation and laboratory testing will be recorded and analyzed.

Total 6 models of asphalt pavement are designed where the heat exchanger which is steel pipes are installed in different depth. Different depths of models with steel pipes analyzed in this study are shown in Table 1.

Sample preparation: The sample preparation is conducted in Highway Laboratory at University Tun Hussein Onn Malaysia. The 6 physical models (pavement) are prepared in different pipe depth. The 3 models are installed with empty steel pipe at different depth while the other 3 models are installed with steel pipes with water solvent as heat exchanger fluid at different depth.
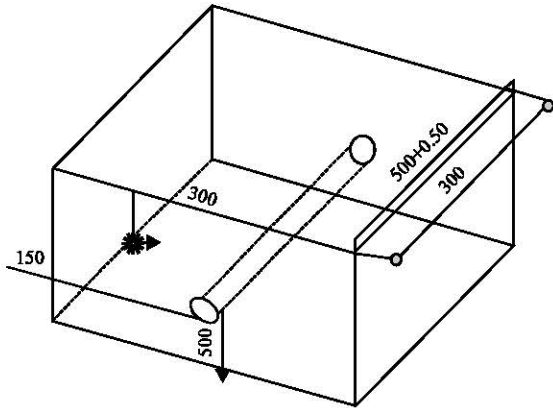
Fig. 2: Steel pipe at depth of 50 mm

Table 1: No. of models in field experiment

Steel pipe	Depth (mm)	Size of model (mm)	Short notation
Empty (E)	50	300×300	E50
100			E100
150			E150
Filled with water (W)	50		W50
100			W100
150			W150

Fig. 3: Steel pipe at depth of 100 mm

Fig. 4: Steel pipe at depth of 150 mm

The preparation of pavement is following public work department of standard specifications. Steel pipes are inserted in the pavement as the heat exchanger pipe. In order to find out the temperature variation within the asphalt pavement and the amount of energy extracted by pavement, the models are placed outdoor with direct sunlight and connected to the data logger. The pavement structure has a dimension of 300×300 mm with a total depth of 150 mm. In the asphalt pavement structure, studies are conducted by varying the pipe depth (50, 100 and 150 mm) from the bottom of pavement layers, keeping the pipe diameter fixed at 15 mm diameter as shown in Fig. 2-4.

Field experiment: This research will conduct a small-scale field test under real atmospheric conditions. The field test setup will consists of asphalt pavement, heat exchanger pipe which is empty steel pipes and steel pipes filled with water, source of heat from sun, thermocouples and a data logger for data collection.

Thermocouples will be inserted in the pavement and connected to the data logger to measure the temperature of heat absorbed in pavement. The samples will be left under the sun for 24 h in 3 days. All results and data will be transmitted directly to data logger. Figure 5 shows the arrangement of asphalt pavement solar collector for field testing in UTHM with empty pipe and pipe filled with water solvent.
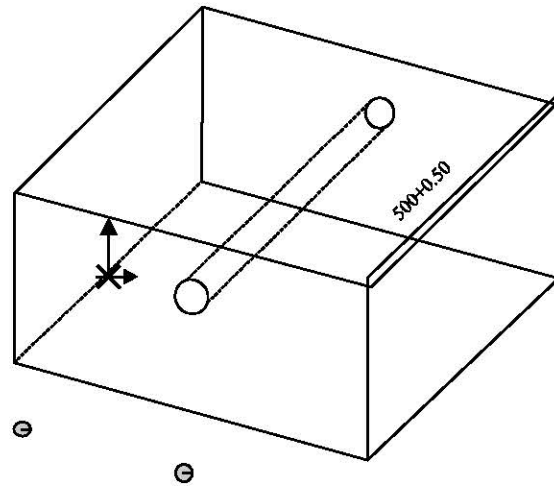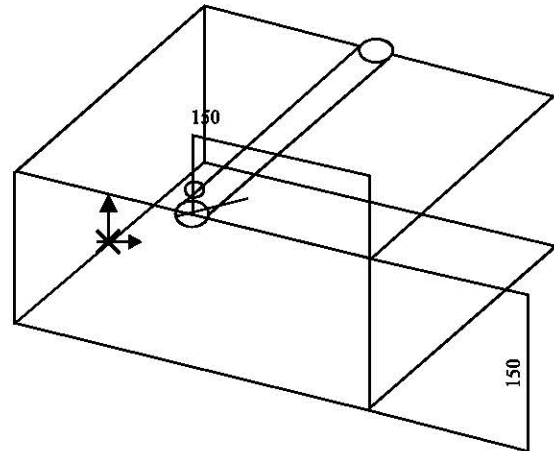

Fig. 5: Arrangement of models connected with data logger in field experiment

Laboratory testing: Laboratory testing for structural analysis is done to determine the maximum strength of steel pipe in pavement to withstand loading. Loading will be applied on samples by using California Bearing Ratio (CBR) machine.

RESULTS AND DISCUSSION

The field experiments and laboratory testing had been conducted and the data had been recorded for analysis. The result had been analyzed in order to achieve the research objectives which are to obtain maximum heat extraction of solar collector in different pipe depth and to determine the maximum strength of steel pipe to withstand loading.

The experimental setup was placed outside for exposure to the sun. In this experiment, the pavement is exposed to the sun and left outside for 24 h from approximately 12-12 am the next day. Data for the heat absorption in asphalt pavement was recorded every 5 min by using data logger. Then, the result were analyzed and graph were plotted to observe at which depth of pavement (50, 100, 150 mm) have the maximum heat extraction. The field experiment was conducted under Batu Pahat, Johor climate condition and the location of study is in UTHM area.

Thermal performance of asphalt layer: The asphalt behavior for surface temperature is shown in Fig. 6. The data were collected for 3 days continuously. Temperature was measured on both sunny and rainy days which represent the real weather condition. The data logger was neither distracted nor shut off during the experiment.

Temperature was low in the morning due to low solar radiation and resulting in less energy being absorbed by water solvent in steel pipe. During daytime, solar radiation is high and the water solvent in steel pipe could absorb a large amount of thermal energy, resulting in a large degree of temperature for heat extraction.

The occurrence of rainfall during the experiment on day 2 for 3 h from 4-7 p.m. had affected the temperature of pavement surface. Further investigation showed that maximum pavement temperature is lowered until the next day after rainfall at 6 a.m. and the rainfall effect had altered the temperature of pavement surface which is up to 40.8°C (after rainfall) from 48.5°C (before rainfall). It shows that rainfall plays a major role as a cooling agent to reduce the surface temperature of asphalt pavement.

Efficiency of water as a heat collector: Table 2 shows the temperature difference of maximum temperature at pavement in different layers with water solvent, empty pipe and ambient temperature for 3 days.

The increment in temperature of pavement with ambient temperature is in between 15-30% which shows that the pavement surface is absorbing the solar radiation and able to increase the surface temperature of pavement. A significant increment in temperature can be achieved
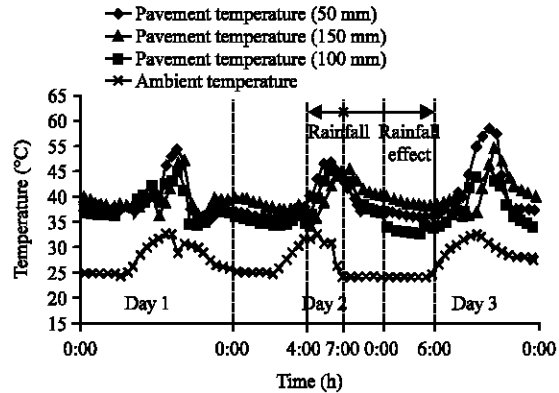

Fig. 6: Thermal performance of pavement layers in 3 different days with depth 50, 100 and 150 mm
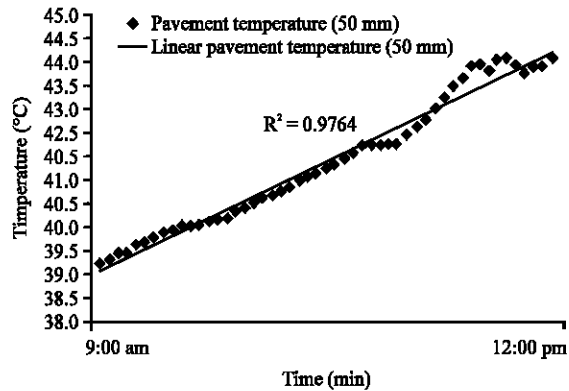

Fig. 7: Increasing rate of pavement temperature

when more heat is applied to the asphalt surface. Thus, the accumulation of heat which causes heat lump can be increase with the performance of asphalt pavement in absorbing heat from radiation.

Thermal pattern in asphalt pavement: The temperature gradient in Fig. 7 shows that the increasing rate of the pavement surface in depth 50 mm for day 3 with coefficient of determination (R^2) value of 0.98 during daytime from 9 am to 12 pm for every 5 min and the decreasing rate of temperature in pavement surface with R^2 value of 0.95 is shown in Fig. 8 during evening from 4 p.m. to 12 am for every 5 min.

This phenomenon shows that the solar radiation from sun increasing the temperature of asphalt pavement surface started from daytime and decreasing in the evening. The ability of water to act as cooling agent had transmitting load to the subgrade. Figure 9 represents the maximum strength of loading that had been sustained by steel pipe in pavement with different depth. Speed up the decreasing rate of temperature in the evening to reduce the surface temperature.

Table 2: Percentage of heat increment in pavement surfaces

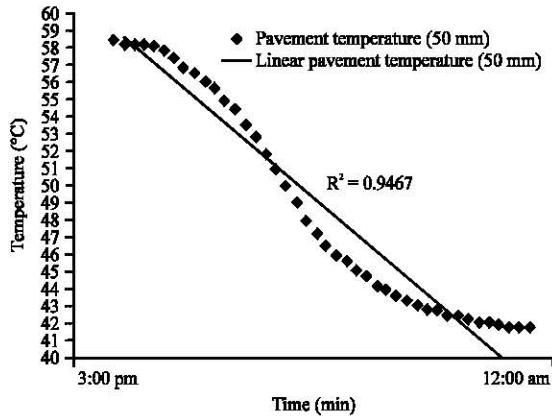| Days	Depth (mm)	Maximum temperature (°C)			Heat increment (%)	
		Pavement with water solvent	Pavement with empty pipe	Ambient	Water solvent vs. ambient	Empty pipe vs. ambient
1	50	56.5	55.4	32.3	24.2	23.1
	100	49.9	49.3	33	16.9	16.3
	150	56.8	55.8	32.3	24.5	23.5
2	50	52.3	54.1	25.1	27.2	29.0
	100	50.4	48.1		25.3	23.0
	150	50.3	52.3		25.2	27.2
3	50	58.9	64.4	32.932.9	26.0	31.5
	100	49.6	55.3		16.7	22.4
	150	54.1	60.2	31.8	22.2	28.4

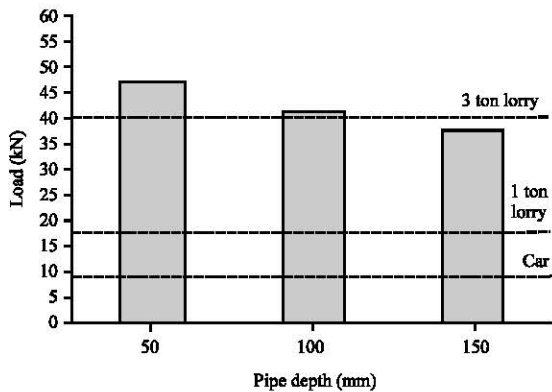Fig. 8: Decreasing rate of pavement temperature

Fig. 9: Maximum strength of pavement in different layer

The coefficient of determination (R^2) measures of how close the data are to the fitted regression line. For increasing rate of pavement temperature during daytime from 9 a.m. to 12 p.m. shown in Fig. 6, the R^2 value indicates that 98% of the response data is around its mean while for the decreasing rate of pavement temperature during evening from 3 p.m. to 12 a.m. in Fig. 7, the value of R^2 is 95%. In general, the higher the R^2 value, the better the model fits the data.

Sustaining load for steel pipe: Road pavement in Malaysia can be classified as flexible pavement and rigid pavement. In this research, flexible pavement was used because it has more flexible surface course and distributes loads over a smaller area. It consists of three main layers, the bituminous surfacing (wearing and binder course), the base or road base and the sub base. It relies on the combination layers for transmitting load to the subgrade. Figure 8 represents the maximum strength of loading that had been sustained by steel pipe in pavement with different depth

Steel pipe at depth 50 mm can sustain the highest loading compared to steel pipe at depth 100 and 150 mm. Steel pipe at depth 50, 100 and 150 mm achieved 47.8, 41.62 and 37.9 kN, respectively thus, passing the maximum loading from car and 1 ton lorry with loading approximately 10 and 16 kN, respectively. For the loading of 3 ton lorry which is approximately 40 kN, only steel pipe at depth 50 and 100 mm can sustained the loading while pipe at depth 150 mm is failed due to the lower maximum loading compared to the loading of 3 ton lorry.

CONCLUSION

For the first objective of this research, determination of temperature for solar collector in different pipe depth in order to obtain its maximum heat extraction we had found out that pavement with steel pipe consisting water solvent at depth of 50 mm has the maximum heat extraction with the temperature of 58.9°C at 3 p.m.

For the second objective which is the determination of strength for steel pipe in pavement to withstand loading, we had done the laboratory testing and the result shows that steel pipe at depth of 50 mm can withstand the highest loading at 47.8 kN compare to pipe depth at 100 and 150 mm with 41.62 and 37.9 kN, respectively at lower loading than pipe depth of 50 mm.

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