Model Development and Performance Enhancement of Solar Pavement Energy Collector

Muhammed Shibili O.[1], Aju S.S.[2]

[1]Student, Dept. of Production Engineering, Government Engineering College Thrissur, Kerala, India
[2]Assistant professor, Dept. of Production Engineering, Government Engineering College Thrissur, Kerala, India

---***---

Abstract - *Asphalt pavement solar collectors consists of tubes installed within the pavement in which a fluid is circulated through the pipe. The incoming solar radiation incident on the pavement surface gradually rises the temperature of the pavement. A conductive heat transfer process take place from surface to circulating pipe due to its temperature difference, which reduces the pavement surface temperature and heats up the circulating fluid in the pipe*

***Key Words*: Asphalt solar collector, reduce temperature on roads, production, reduce rutting of roads, enhancement methods**

1. INTRODUCTION

Asphalt pavement solar collectors consists of tubes installed within the pavement in which a fluid is circulated through the pipe. The incoming solar radiation incident on the pavement surface gradually rises the temperature of the pavement. A conductive heat transfer process take place from surface to circulating pipe due to its temperature difference, which reduces the pavement surface temperature and heats up the circulating fluid in the pipe. Therefore we can store or reuse the incident solar radiation in a efficient manner. The primary advantages of the system is that the heat obtained is cost efficient and a clean energy source. Secondly, the heat extraction results in reduced delamination and rutting of roads which in turn increases the life of roads.

The pavement surface temperature will rise up to 60°C in summer days with an enhancement in air temperature which is commonly called the heat island effect. By implementing the cooling system to the pavements we can reduce the surface temperature up to 7 °C in summer days. And we can use the heat energy for heating purpose of the same pavements in the winter season with the help of a efficient heat storage system. In winter season there have significant safety risks due to snow fall and ice on pavements. Which leads slippery road conditions and causes accidents.

Asphalt in its simplest form consists of aggregates which are bound together by means of a binder (i.e. Bitumen). The term 'visco-elastic' is usually indicates bitumen materials have both viscous and elastic behavior; viscous at high temperature and elastic at low temperature.

2. LITERATURE REVIEW

Solar collectors are devices which are used to collect the solar energy from the sun and are used for different purposes such as solar heating, solar drying, solar power generation etc. There are different types of solar collectors. Flat plate collectors, parabolic dish collectors, concentrating and non-concentrating collectors are some of them.

Research in the field of asphalt pavements was done by Barber et. al. (1957). Barber correlated pavement surface temperatures and temperatures at 3.5inch depths with the weather parameters wind speed, precipitation, air temperature, and solar radiation.

The snow melting process on asphalts pavements as solar collectors by experiments and numerical simulation done by Chen [3] et al. gave the temperature statistics on the pavement surfaces. The variation of APSC behavior with parameters has also been extensively. Studied theoretically .in the work of Diefenderfer [4] et al. A two- dimensional mathematical model was developed for predicting the daily maximum and minimum pavement temperature and validated using data from the variation of APSC behavior with parameters has also been extensively. Studied theoretically .in the work of Diefenderfer [4] et al. A two-dimensional mathematical model was developed for predicting the daily maximum and minimum pavement temperature and validated using data from the Virginia smart road

Zhou [5] et al. used data collection from four pavement sections and predict equations to gradients in asphalt pavements the study also considered solar radiation for cloudless skies

Recently, Bobes [9] et al. found out the variation of asphalt thermal conductivity affects the temperature with increasing depth, without producing noticeable changes in surface temperature. Copper is the material used in the pipe network which achieves greatest efficiency of the system. Spacing between the pipes and also the depth of pavement influence the temperature distribution in the collector. The collector efficiency depends strongly on flow rate: as flow rate increases, heat transfer between fluid and the pipe increases, but the temperature increment undergone by the fluid decreases.
Concrete cladding system can be converted into concrete solar collectors by embedding pipes in the concrete which can be used paper was done by O'Hegart [7] et al

Guldentops[1] et al., studied the energy balance at the surface using N-factor represents the ratio of daily mean air temperatures to daily mean pavement temperatures. They are interested in the short time span, hour rather than months

Anastasio [13] et al., showed that lime stone mixes behaved differently from those prepared with light weight aggregate. For the lime stone mixes, thermal conductivity varied as much as 20 percent as the asphalt content was varied between 3.5 percent and 6.5 percent. Little variation of thermal conductivity in the lightweight aggregate mix was observed with comparable changes in asphalt content. Specific heat was approximately 60 percent greater in the lightweight mix than the limestone mix. They found that which is primarily due to the unit weight difference. A significant difference was noted in the diffusivity of the limestone course and the limestone base course, apparently due to graduation and aggregate size.

Straub [2] et al. studied asphalt pavements considered with both 6 and 12 inch thick dense graded pavements at various depths. A computer model was developed to predict pavement temperatures based on air temperature and solar radiations. The study showed that surface temperature measurements must be made at the surface to achieve a good correlation with solar radiation received at the site. It was mentioned that temperature at various depths of an asphalt pavement are independent of the thickness of the asphalt pavement surface. Results of the study also shows that solar radiation had a greater effect on pavement surface temperature than air temperatures. The numerical model used by Straub subdivided the asphalt pavement in a column of nodes with a cross sectional area of one square feet. The nodes were set at the same depths as the thermocouple had been in the actual test section simulation of the model was initiated with guessed temperature at each node. This model provided a good correlation between temperatures and those predicted.P.K Nicolas [13] et al. designed asphalt collector model in COMSOL and analysed about the heat extraction, outlet temperature and the efficiency involved by doing a sensitivity analysis for all the parameters studied. Mallick [14] et al. worked with a finite element modelling and testing with small and large scale asphalt pavement samples. Copper pipes embedded in the samples are considered as heat exchangers. The temperature rise noted at the pipe outlet of asphalt pavement is used as an indicator of efficie

Wang [8] et al. validated the parameters that are critical in the asphalt collector, a finite element model is developed to predict the thermal response of the heat-conducting device compared to the conventional asphalt mixture

Wu Shaopeng [15] et al. observed the thermal response of asphalt pavements as solar collector by application of small scale asphalt slabs. The copper tubes were embedded in the asphalt slabs for the purpose of water circulation and the thermal sensors were also embedded in different depths for temperature measurement during slab preparation. A laboratory simulation test was performed to heat up the asphalt slabs. The thermal energy stored in the slabs was collected by the circulating water. The effect of flow rate, the time for starting collection and the initial temperature distribution of the slabs on the process of heat collection were evaluated. The results shows asphalt solar pavement can be cooled by the solar collector thus is good for reducing heat islands in a city.

3. METHODOLOGY

The design and fabrication of asphalt pavement energy collector involves the following steps.

3.1 Journals which include the similar topics are collected from International journals Applied Energy

3.2 Experimental analysis of asphalt solar pavement collector

Solar collector having required dimension are fabricated with a wooden frame of dimension 100cm length, 80 cm width and 10 cm height. An insulating layer of polyurethane rigid foam is used for 3cm at the bottom of the wooden chamber. Above the insulating layer granular material is used to up to 6cm height. A copper tube of diameter 3/8 inch with cross grid setup is placed above the base sub granular layer. An experimental study was done without asphalt surface at this stage.

Table -1: Without asphalt using polyurethane rigid foam as insulator

Water flow through tube		temperature(K)		
Flow rate (Kg/s)	Time (Hrs)	Inlet	Outlet	difference
0.0026	11:30	30.8	40.8	10
	12:00	31.2	41.8	10.6
	12:30	31.4	42.3	10.9
	1:00	32.5	43.4	10.9
	1:30	32.1	43.1	11
0.0018	11:30	30.5	43.4	12.9
	12:00	31.3	43.8	12.5
	12:30	31.5	44.1	12.6
	1:00	32.6	44.8	12.2
	1:30	32.3	43.5	11.2
0.0014	11:30	30.7	46.1	15.4
	12:00	31.6	47.2	15.6
	12:30	31.4	48.3	15.9
	1:00	32.8	50.1	17.3
	1:30	32.7	48.3	15.4

Table -2: Experiment conducted with asphalt on pavement surface with a flow rate of 0.0026 kg/s

Time (Hrs)	Solar Intensity (W/m²)	Air velocity m/s	Temperature (°C)			Temperature difference	Efficiency
			Average asphalt surface temperature	Inlet	Outlet		
9:00	346	1.1	32.4	30.2	31.1	0.9	2.07
9:30	612	1.2	35.9	30.5	34.2	3.7	4.96
10:00	214	1.3	35.7	30.6	33.5	2.9	13.92
10:30	705	1.2	35.5	30.8	34.5	3.7	4.20
11:00	835	1.2	39.2	33.2	38.1	4.9	4.86
11:30	913	2.0	46.7	34.1	44.0	9.9	10.11
12:00	963	1.9	48.6	34.3	47.2	12.9	12.72
12:30	667	1.8	49.5	34.5	47.5	13.0	21.72
1:00	885	1.7	51.1	35.0	49.4	14.4	16.33
1:30	917	1.9	53.2	38.0	51.3	13.3	14.36
2:00	514	2.3	48.7	36.1	46.4	10.3	24.49
2:30	258	2.9	46.8	36.1	44.3	8.2	16.56
3:00	532	2.5	44.6	35.1	43.1	8.0	15.92
3:30	418	2.7	43.1	34.2	42.5	8.3	23.13
4:00	218	3.3	39.9	32.8	39.5	6.7	21.71
4:30	180	3.0	35.2	31.2	34.4	3.2	9.20
5:00	147	3.1	33.5	30.3	31.5	1.2	4.44

Table -3 : Experiment conducted with asphalt on pavement surface with a flow rate of 0.0018 kg/s

Time (Hrs)	Solar Intensity (W/m^2)	Air velocity (m/s)	Temperature(°C)			Temperature difference	Efficiency
			Average asphalt surface temperature	Inlet	Outlet		
9:00	312	1.1	33.2	30.1	32.1	1.0	5.40
9:30	396	1.1	35.5	30.1	34.3	4.2	9.46
10:00	412	1.3	36.8	30.2	35.4	5.2	11.44
10:30	528	1.5	39.2	30.4	38.1	7.9	13.60
11:00	595	1.1	44.4	33.1	42.4	9.3	15.62
11:30	765	2.1	48.3	34.2	45.1	10.9	14.82
12:00	895	2.3	49.5	35.0	47.2	12.2	13.51
12:30	928	2.1	53.7	35.1	51.4	16.3	18.55
1:00	988	1.7	55.9	36.0	54.7	18.7	19.24
1:30	981	2.4	55.4	36.2	54.1	17.9	20.28
2:00	975	2.5	54.5	35.0	53.2	18.2	20.82
2:30	900	2.6	52.1	34.1	50.2	16.1	19.67
3:00	895	3.1	49.8	33.0	47.1	14.1	17.45
3:30	732	3.0	45.6	32.5	43.3	10.8	16.06
4:00	631	2.5	42.4	31.7	40.2	8.5	13.77
4:30	512	2.7	39.8	30.3	38.5	8.2	16.43
5:00	218	2.5	37.2	30.1	35.1	5.0	10.59

Table -4 : Experiment conducted with asphalt on pavement surface with a flow rate of 0.0014 kg/s.

Time (Hrs)	Solar Intensity (W/m^2)	Air velocity (m/s)	Temperature(°C)			Temperature difference	Efficiency
			Average asphalt surface temperature	Inlet	Outlet		
9:00	342	1.0	33.2	30.1	32.1	2.0	4.75
9:30	525	1.0	34.5	30.2	33.4	3.2	4.92
10:00	596	1.2	38.4	31.1	36.2	5.1	7.42
10:30	703	1.5	41.6	31.1	39.3	8.2	10.49
11:00	885	1.4	44.7	32.2	42.5	10.3	10.42
11:30	925	1.5	49.4	32.2	48.3	16.1	16.95
12:00	964	1.6	53.8	33.3	50.4	17.1	18.74
12:30	988	1.8	57.9	33.4	55.1	21.7	24.96
1:00	992	1.9	59.7	34.4	58.1	23.7	28.23
1:30	985	2.0	58.5	34.9	57.4	22.5	27.04
2:00	926	2.4	57.1	33.9	56.1	22.2	29.73
2:30	898	2.8	53.5	33.8	51.3	17.5	22.67
3:00	812	2.6	46.7	33.4	47.5	14.1	17.62
3:30	729	2.9	44.4	32.3	44.2	11.9	16.38
4:00	730	2.4	42.8	31.2	40.3	9.1	12.04
4:30	612	2.1	39.2	31.1	38.1	7.0	10.54
5:00	398	1.9	36.6	30.2	35.2	5.0	11.65

4. CONCLUSIONS

On the experimental analysis the temperature rise of both asphalt pavement and without asphalt pavement surfaces are obtained for three different flow rates, as we obtained in the numerical analysis the temperature rise was increases with decrease in flow rates. The maximum temperature difference between asphalt and without asphalt surfaces for the flow rates 0.0026 kg/s was 2.3°C,0.0018 kg/s was 6.7°C,0.0014 kg/s was 7.1°C was obtained for an average solar intensity of 950 W/m2 for the time interval of 11:30 AM to 1:30 PM.

The efficiency of asphalt pavement surface were obtained for the three flow rates, the maximum efficiency for 0.0026 kg/s was 24.49%. For 0.0018 kg/s was 20.82%, for 0.0014 kg/s was 29.73%. Maximum efficiency was obtained for the minimum flow rates and which have the maximum temperature rise in water 22.5°C.

The hot water can be used for different purposes like food production, electricity generation, pre heating etc.

REFERENCES

[1] Gert Guldentops, Alireza Mahdavi Nejad, cedric vuye, Wim vannima Rahbar(2016)Performance of a solar energy collector: Model development and validation, Applied Energy

[2] Shaopeng Wu, Hong Wang, Mingyu Chen, Yuan Zhang (2011).Numerical and Experimental Validation of full depth asphalt slab using capturing solar energy, *Applied Thermal* Engineering

[3] Zhihua Zhou, Xiaojuan Wang, Xiaoyan Zhang, Guanyi Chen, Jian Zuo, Stephen Pullen(2010).Effectiveness of pavement-solar energy system – an experimental study, Applied Energy

[4] Brain K, Diefenderfer (2006).The variation of asphalt solar collector behavior with parameters, Applied Energy

[5] Jiyun Qin, Eric Hu Graham J. Nathan, LeiChen(2017).Concentrating or non-concentrating solar collectors for solar Aided Power Generation, Energy Conversion and Management

[6] Himangshu Bhowmika, Ruhul Amin. (1971)Efficiency improvement of flat plate solar collector using reflector, Energy Reports.

[7] Richard O'Hegarty Oliver Kinnane Sarah J. Mc Cormack. (2017).Concrete solar collectors for façade integration: An experimental and numerical investigation. Applied Energy

[8] Mingyu Chen, Shaopeng Wu, Hong Wang, JizheZhang.(2012).Study of ice and snow melting process on conductive asphalt solar collector, Solar Energy Materials and Solar Cells

[9] Vanesa Bobes-Jesus Pablo Pascual-Muñoz Daniel Castro-Fresno Jorge Rodriguez-Hernandez. (2013),Asphalt solar collectors: A literature review, Applied Energy