NUMERICAL STUDY OF HEAT TRANSFER ENHANCEMENT IN ASPHALT COLLECTOR USING CuO NANOFLUID

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"To my beloved mother and father"

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ABSTRACT

This study investigates the heat transfer enhancement in asphalt collector by using CuO nanofluid. In this study the first approach is based on increasing the heat gain which is captured by solar energy on asphalt pavement. The second approach is related to accelerate the period of snow melting. Numerical simulation method has been used to predict the temperature distribution in the asphalt collector. The study was conducted at unsteady state, laminar fluid flow with small and large scale of geometry. Certain boundary conditions and assumptions to solve the governing equations were implemented by using finite volume method. Computational fluid dynamics software involves ANSYS FLUENT 14.0 was employed to perform the investigation numerically. Using nanofluid is considered as a positive way to improve the performance of melting system. The CuO Nanofluid from 1 to 4% volume fraction with particle diameter of 50 nm dispersed in a base fluid (water) were used to improve the heat transfer of asphalt collector and thus resulting in an augmentation of efficiency of asphalt collector. The rise in temperature of nanofluid as a result of flow through asphalt pavement was used as an indicator of efficiency enhancement of heat capture. The results of simulation for both small and large scale geometries show that the use of nanofluid can significantly enhance the efficiency of heat capture by bringing high amount of solar energy out. It is also noticed that the asphalt collector provides us a better alternative method for snow melting. Asphalt pavement temperature distribution was evaluated and the non-uniform temperature in the asphalt pavement is noticeable.

ABSTRAK

Kajian ini mengkaji peningkatan pemindahan haba dalam pengumpul asfalt dengan menggunakan bendalir nano CuO. Dalam kajian ini pendekatan pertama adalah berdasarkan kepada peningkatan keuntungan haba yang ditangkap oleh tenaga solar pada turapan asfalt. Pendekatan kedua adalah untuk mempercepatkan tempoh salji lebur. Kaedah simulasi berangka telah digunakan untuk meramal taburan suhu dalam pengumpul asfalt. Kajian ini telah dijalankan pada keadaan tak mantap, aliran bendalir lamina dengan skala geometri yang kecil dan besar. Syarat sempadan tertentu dan andaian untuk menyelesaikan persamaan yang mengawal telah dilaksanakan dengan menggunakan kaedah isipadu terhingga. Perisian melibatkan ANSYS FLUENT 14.0 telah digunakan untuk melakukan siasatan secara berangka. Penggunaan bendalir nano dianggap sebagai cara yang positif untuk meningkatkan prestasi sistem lebur. Pecahan isipadu bendalir nano CuO daripada 1 hingga 4% dengan diameter zarah 50 nm tersebar dalam bendalir asas (air) telah digunakan untuk meningkatkan pemindahan haba pengumpul asfalt dan seterusnya meningkatkan kecekapan pengumpul asfalt. Kenaikan suhu bendalir nano yang terhasil daripada aliran melalui turapan asfalt digunakan sebagai penunjuk kepada peningkatan kecekapan penangkapan haba. Keputusan daripada simulasi bagi kedua-dua geometri berskala kecil dan besar menunjukkan bahawa penggunaan bendalir nano dapat meningkatkan kecekapan penangkapan haba secara signifikan dengan mengeluarkan sejumlah tenaga solar yang banyak. Kajian juga mendapati bahawa pengumpul asfalt memberikan kita satu kaedah alternatif yang lebih baik untuk peleburan salji. Pengedaran suhu bagi turapan asfalt telah dinilai dan suhu yang tidak seragam dalam turapan asfalt adalah ketara.

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LIST OF ABBREVIATIONS

AC	-	Asphalt Collector
Ar	-	Snow Area Ratio
ASC	-	Asphalt Solar Collector
CAC	-	Conductive Asphalt Collector
NF	-	Nanofluid
NP	-	Nanoparticle
Nu	-	Nusselt Number
R	-	Reynolds number

LIST OF SYMBOLS

Cp	-	Specific Heat Capacity (J/kg.K)
H	-	Heat Transfer Coefficient ($W/m^2.K$)
K	-	Thermal Conductivity (W/m.K)
L	-	Liter
M	-	Molecular Weight of base Fluid
T	-	Temperature (K)
q	-	Heat Gain w/m^2
t	-	Time
u	-	Velocity in x direction
μ	-	Dynamic viscosity (kg/m.s)
ρ	-	Density (kg/m^3)
Φ	-	Particle volume fraction

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Heat transfer knowledge has been considered for decades. High efficiency of heat transfer has improved not only performance of the devices, but also fuel consumption. The efficiency of many devices which are needed to be heated or cooled is involved to heat transfer performance. The necessity of high thermal performance thermal systems has been eventuated finding different ways to enhance the heat transfer rate.

The reduction of fossil fuel consumption and gas emission to the atmosphere motivates research and development of new energy generation methods: renewable, clean, and respectful of the environment. Asphalt pavement has gained more and more attention in recent years as an interesting new renewable energy source [1]. The sun provides a cheap and abundant source of clean and renewable energy.

The radiation from the Sun reaching the Earth generates heat on the ground. The solar radiation depends on the latitude and the angle of incidence. From a

Meteorological perspective, radiation variation in world for horizontal surfaces and as it seems the central and northern world. As shown in Figure 1.1, this is measurements of the NASA Research Center.

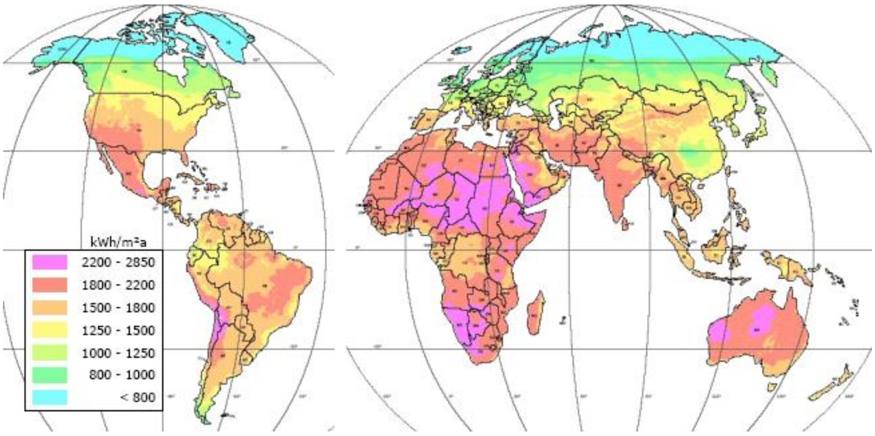

Figure 1.1 The average annual solar radiation variations in world

In asphalt solar collector (ASC), the fluid is circulated through a series of pipe circuits laid below pavement surface. The irradiation from the sun and the atmosphere is absorbed by the pavement and then the fluid through the pipes brings the solar energy out and stored in the ground over summer time. Hence, the energy is used for the heating of adjacent buildings as well as to keep the pavement, ice-free directly in winter [4]. Numerous studies have been conducted on the amount of energy that can be extracted, the amount of energy that is needed to keep an asphalt road free of ice, and the effect of energy transfer on temperature distribution along the depth of asphalt pavements [5]. ASC provides us a better alternative method for snow melting because of such system generally has higher energy efficiency than boilers or electrical heaters. Furthermore, by extracting heat in the summer and providing heat in the winter as shown in Figure 1.2.

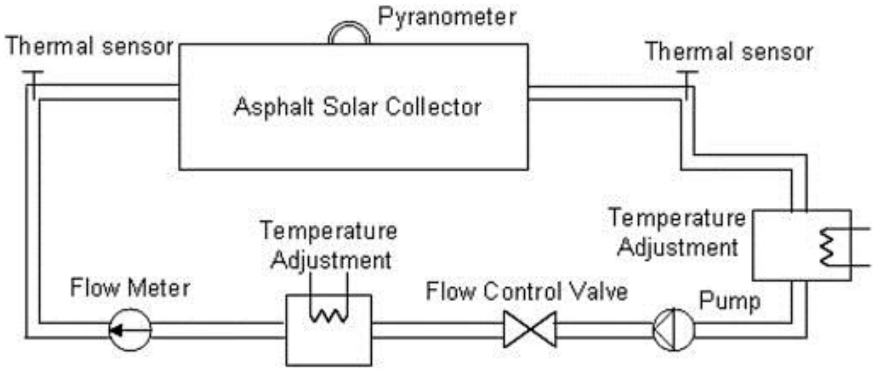

Figure 1.2 Schematic diagrams of the solar collecting device and snow melting

Asphalt solar collector (ASC) provides us a better alternative method for snow melting. The higher fluid temperature is a positive way to improve the performance of snow melting system. Asphalt concrete is widely used in parking lots, tarmacs, airport runway, bridge deck, roadways, etc. Therefore, it is desirable that ice and snow be removed effectively to keep asphalt pavement free [2].

Asphalt solar collectors consist of pipes embedded in the pavement with a circulating fluid inside as shown in Figure 1.3 Solar radiation causes an increase in pavement temperature. Due to the temperature gradient between the fluid circulating through the pipes and the pavement, a heat transfer process occurs from pavement to a fluid which leads to a drop in pavement temperature and an increase in fluid temperature. This drop in asphalt temperature contributes to mitigate the heat island effect and reduce the risk of permanent deformations. However, what makes asphalt solar collectors really interesting is their ability to use the temperature rise undergone by the circulating fluid to harness energy. Asphalt solar collectors are usually coupled with low temperature geothermal heat pumps, obtaining reasonable efficiency and operating costs. The energy obtained from asphalt solar collectors is generally used for snow-melting systems or to maintain thermal comfort of adjacent buildings. There are also concrete solar collectors, but because of the black color, the asphalt solar absorption coefficient is higher than concrete [6].

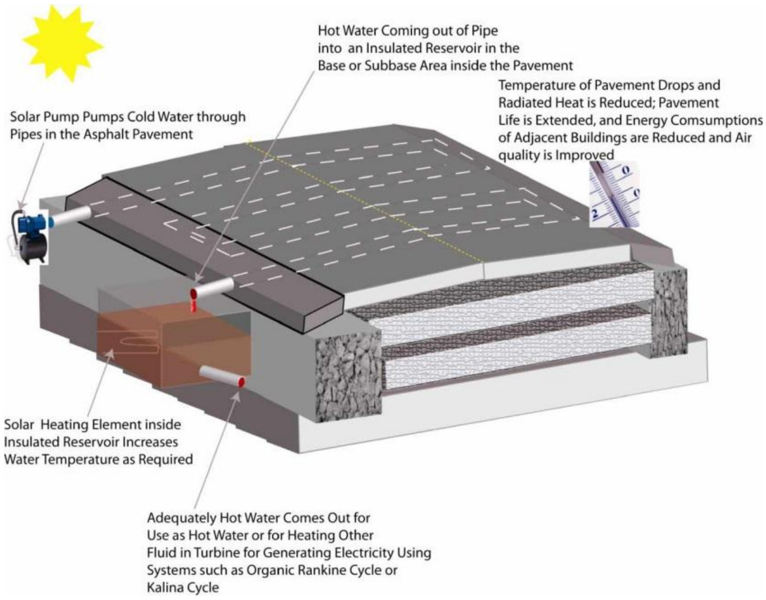

Figure 1.3 Concept of harvesting energy from pavements and reducing pavement temperature

The passive techniques include methods to modify the fluids' properties, surface shape, roughness or external attachment to increase the surface area, and make the flow laminar and turbulent. However, conventional heat transfer fluids such as water his poor thermal performance due to his low thermal conductivity, therefore it should add the nanoparticles to change the fluid character to be nanofluid to increase the thermal conductivity of the these fluids.

Nanofluids are colloidal mixtures of nanometric metallic or ceramic particles in a base fluid, such as water, ethylene glycol or oil. Nanofluids possess immense potential to enhance the heat transfer character of the original fluid due to improved thermal transport properties and according to passive studies that the Non-metallic materials, such as alumina Al_2O_3, CuO, TiO_2 and carbon that possess higher thermal conductivities than the conventional heat transfer fluids.

1.2 Problem Statement

It is a major societal problem to provide a sustainable supply of energy. To make good use of solar energy, researches into asphalt pavements used as solar collector have been conducted. It is indicated that Asphalt Solar Collector (ASC) could be used for heating and cooling the adjacent buildings as well as keeping the pavement ice free. To improve traffic safety in the late fall, winter, and early spring, during periods of snow, sleet, and freezing rain. Preventing the snow accumulation and ice formation on roads, especially on some critical sections including bridges and ramps, is of high priority to improve winter transportation safety [2].

On the other hand the Asphalt pavement surface temperature can reach up to 70 °C in summer inducing a rise in temperature of the air above, which is generally known as the heat island effect. It causes an increase in power consumption due to the use of air conditioning and a decrease in air quality in cities. Moreover, pavements under such high temperatures are prone to suffer from rutting. In particular, the thermal oxidation rate doubles with each 10 K increment in temperature [7].

Moreover, the routine heat transfer fluid does not satisfy the necessity of a great heat transfer with high efficiency. In this case, many investigations have been done to enhance the heat transfer by using water as a working fluid. However, water has low thermal conductivity. So the investigators are turning to the solids with high thermal conductivities and methods to mix these materials with water as a base fluid. The composite material in nanoscale mixed with base fluid to produce medium has a term of "nanofluid" to enhance the heat transfer properties. Until now no research reported on using nanofluid in asphalt solar collator. This project will focus on heat transfer enhancement using nanofluid.

1.3 Application of the Study

The sun provides a cheap and abundant source of clean and renewable energy. Solar cells have been used to capture this energy and generate electricity. A more useful form of “cell” could be asphalt pavements, which get heated up by solar radiation. The “road” energy solar cell concept takes advantage of a massive acreage of installed parking lots, tarmacs, and roadways. The heat retained in the asphalt mixture can continue to produce energy after nightfall, when traditional solar cells do not function. The idea of capturing energy from pavement not only turns areas such as parking lots into an energy source, but also could cool the asphalt pavements, thus reducing the urban heat island effect, the type of asphalt solar collector combined with turbine to produce electrical energy is called (Roadway power system) as shown in figure 1.4.

Figure 1.4 Roadway power systems

One of the pioneer applications on an asphalt solar collector in Switzerland they are called (smart bridge) as shown in figure 1.5, this system combined with borehole heat exchanger of ground source heat pump system.

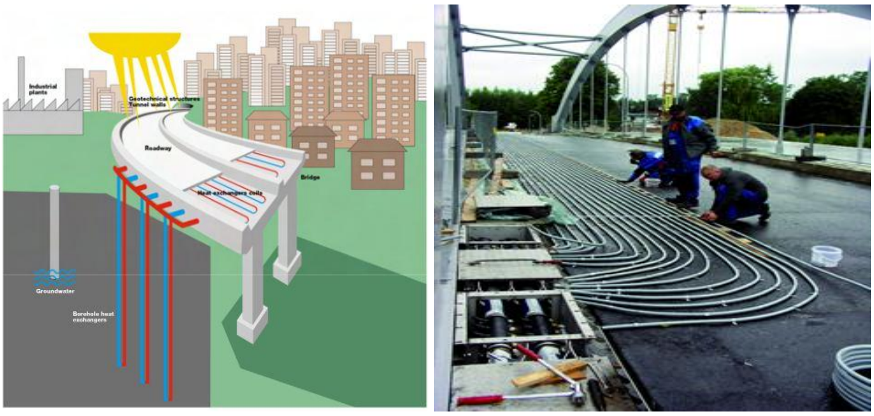

Figure 1.5 Smart Bridge

The main task was to investigate the application of an asphalt solar collector for heat capture and a ground source heat pump with borehole storage with the intention of using that heat for domestic hot water and air condition as shown below in figure 1.6.

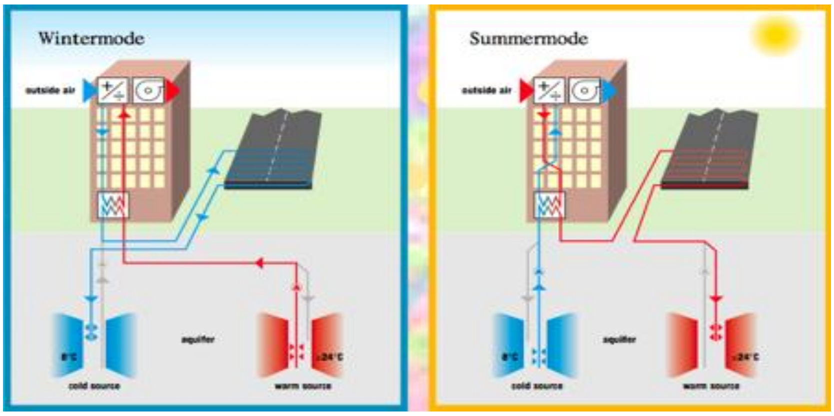

Figure 1.6 Air conditioning for buildings by using asphalt solar collector

The system uses an existing lot, so does not require purchase or lease of new real estate (as would be needed for a solar “farm” installation). The system has no visible signature that is; the parking lot looks the same. This compares well against rooftop silicon panels that are often bulky and unattractive. The energy system can be installed. The captured energy from heated asphalt pavements can be used for relatively simple applications, such as heating of water, to sophisticated applications, such as snow melting in the winter, generating electricity through thermo-electric generators in the summer [8].

1.4 Objective of the Study

The objective of the present study is

- To improve the thermal efficiency of asphalt collector using nanofluid.
- To analyze the performance of asphalt collector.

1.5 Scope of Study

The scope of the present study is

- Using CuO nanofluid with volume fraction at the range from 0% to 4%.
- Incompressible fluid flow.
- Laminar flow.
- Unsteady state flow.
- Using CFD Ansys fluent 14.0.

1.6 Dissertation Outline

This thesis is divided into five chapters as follows:

Chapter 1 represents the problem statement and scope of this study. Applications of the study and the objectives of the project are reported.

Chapter 2 contains the literature review which is related to the temperature distribution and enhances heat transfer in asphalt collector geometries involving experimental and numerical studies for three-dimensional geometries. The parameters that related to the thermal conductivity, pipe length, pipe spacing and inlet temperature fluid, while the last section is related to nanoparticles and nanofluids parameters, application, production and thermo physical properties.

Chapter 3 focuses on the mathematical and theoretical aspects governing the convection heat transfer for three-dimensions in asphalt collector. This chapter shows the numerical procedures for solving the present problem in details as well as the assumptions and limitations of boundary conditions for the computational domain are also mentioned. Furthermore, the analysis and equations of nanofluids thermophysical properties are presented according to their diameter and volume fraction.

Chapter 4 the first section presents the code validation results. The second section introduces the results of the present numerical work to investigate the effects of nanofluid with different nanoparticle volume fractions.

Chapter 5 summarizes the conclusions obtained from the numerical simulation with related suggestions for future work.

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