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Experimental study of slab solar collection on the hydronic system of road

Qing Gao [a], Yong Huang [a], Ming Li [a,*], Yan Liu [a], Y.Y. Yan [b]

[a] Jilin University, Changchun 130025, China

[b] University of Nottingham, Nottingham NG7 2RD, UK

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Abstract

This paper studied the slab solar collection (SSC) process, which is one of the essential compositions of road hydronic ice-snow melting (HISM) system that stores solar energy in summer to melt ice and snow on the road in winter. Its aim is to find out the heat transfer characteristic of the SSC and heat collecting efficiency and the influence of pipe spacing and flow rate by experiment. As shown in experimental results, the average heat collecting capacity is about 150–250 W/m^2 in natural summer condition, while the solar radiation intensity is about 300–1000 W/m^2. It is shown that the increment of fluid flow results in the increment of heat collection efficiency, while the increment of pipe spacing results in the decrement of the efficiency in experiment modes. The results show that the road slab can obtain about 30% solar heat in summertime, and the solar collection can lower the pavement temperature and reduce the insolation weathering.

Keywords: Slab; Solar energy collection; Heat transfer characteristic; Heat collecting efficiency

1. Introduction

Ice-snow melting system on the road coupled with SSC and seasonal underground thermal energy storage (UTES) will become a sustainable and important measure in the future transportation because of the contamination of chemical agents for ice-snow melting. The hydronic underroad heating system has been used for a number of decades as a means of controlling snow and ice formation on a variety of pavement surfaces such as roads, concrete bridge pedestrian walkways, airport aprons and helicopter pads (Yehia et al., 2000; Zwaryez, 2002; Derwin et al., 2003). Preventing 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. As a substitute for chemical agents, automatically controlled HISM systems have been proposed recently to prevent icing and melt snow on the bridge surfaces. By eliminating salt, such systems can reduce the rate of corrosion and extend the life of the bridge adequately. In such systems, heated fluid is circulated in a series of coil pipes, which usually laid in serpentine configuration, just below surface, to melt snow and ice in winter. Recently, designers pay more attention to the use of existed pipes in the road slab, which are used to collect solar energy in summer and store it into ground for the supplemental use in winter (Derwin et al., 2003). The UTES, characterized by seasonal thermal energy storage, is an excellent option, and the stored energy can compensate the temporary imbalance of supply-and-demand or reduce the consumption of geothermal energy in long period operation of ground source heat pump systems (Liu et al., 2007).

In recent years, researchers from America, Japan, and North Europe have been researching the HISM, and concerning about the seasonal utilization of SSC and UTES

* Corresponding author. Tel.: +86 431 85095196.
E-mail address: limingtiger@jlu.edu.cn (M. Li).

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(Liu et al., 2007), such as SNOWFREE demonstration and experimental engineering projects of melting ice-snow in O'Hare international airport runway of Chicago in America, the SERSO installation on the Därligen bypass on the A8 Express road, ice-snow melting system by hydronic fluid in the parking apron at Gardermoen in Norway, the Gaia snow-melting system for highway and ramp in Ninohe City of Japan, and a snow melting and heating system for the airport at Goleniow, Poland. From 1992, the American Heated Bridge Technologies (HBT) plan that systematically researched HISM problems on road and bridge has been come into effect under the sponsorship of the Department of Energy, Federal Highway Administration of Department of Transportation and National Fund of Fundamental Research (Rees et al., 2002). From 1994 to 1999 HISM systems on road and bridge were demonstrated in five states. In Japan, with the promotion of Organization for Economic Co-operation and Development (OECD) and International Energy Agency (IEA), the first system of automatic collecting and storing energy and snow-melting by hydronic fluid, which is called Gaia System, was installed in 1995 in Ninohe by the National Institute for Resources and Environment (NIRE).There have been dozens of experimental researches in this system (Morita and Tago, 2000).

The researching work on hydronic snow-ice melting system on road and bridge has been carried on since 1998 in Oklahoma State University (OSU) of America under the sponsorship of the Department of Energy, Federal Highway Administration of Transportation Department and Transportation Department of Oklahoma State (Xiaobing et al., 2007). The experimental system, a full-scale bridge melting snow system, was the largest one in the world. The ice-snow melting system was developed according to the local climate conditions, and the system combined with the borehole heat exchanger of ground source heat pump system. This research analyzed heat transfer of porous medium, established the model of melting ice-snow and model of collecting and storing thermal energy, and analyzed the heat transfer on the road by the finite element method.

From 1997, researches of Jilin University have been studying the utilization of geothermal energy, the underground heat transfer, ground source heat pump, UTES and HISM system (Qing et al., 2009). Researchers of Tianjin University have researched road ice and snow melting based on low temperature geothermal tail water experimentally, and analyzed dynamic melting processes of crushed ice, solid ice, artificial snow and natural snow (Wang et al., 2008). Researchers from the Third Co. Ltd., China Zhongtie Major Bridge Engineering Group, studied the bridge surface deicing system in Yuebei Section of Jingzhu Highway by comparing present highway and bridge snow-melting technologies (Shunqing and Xi, 2008). The corresponding deicing program was established to enhance the traffic quality and reduce the quantity of accident.

Takashi Asaeda, etc. (Asaeda et al., 1996) studied the heat storage with various pavement materials in summer days, and analyzed the effect on lower atmosphere. Their research indicated that asphalt could absorb much more solar energy than other materials in summer, and could emit more heat into atmosphere in winter. Bilgen and Richard (2002) had taken the horizontal concrete slabs as solar collector. They analyzed the transient heat transfer in the slab theoretically and experimentally, and optimized energy storage density and the thermal performance. A model for calculating available heat energy from solar energy in road imbedded pipe was established by Warsaw University of Technology (Mariuse and Roman, 2003). They studied non-transparent solar collector and instantaneous heat transfer of large heat capacitance collector. Furthermore it took into account instantaneous shadow of the vehicles, influence of re-convection and pure plane collector.

In fact the technology of using SSC and UTES has been presented (Qing et al., 2009), while fewer efforts have focused on the foundational research of the thermal performance of solar collection in the slab practically. This paper studied the heat transfer performance, surface temperature and flow characteristic of hydronic fluid in different spacing. This investigation and exploration not only benefits the road traffic safety engineering but also provides a reference basis for further study and application of SSC in a saving building.

2. Experimental facilities and method

The experimental system of SSC was built with cement concrete and hydronic pipe imbedded in it. There are three different serpentine pipe spacing. The size of solar collection slabs is 1.2 m × 0.6 m by length and width. The outer diameter of pipe is 20 mm, and the inner diameter of pipe is 16 mm. The experimental system is shown in Fig. 1. The solar collection slab consists of three layers, road surface layer, cushion layer and roadbed layer from top to bottom, and the thickness is 30 mm, 40 mm and 8 mm respectively. The hydronic pipes were set between the road surface layer and the cushion layer, and arranged in serpentine form which the pipe spacing is 90 mm, 120 mm and 150 mm respectively. The main test apparatus included solar collection slabs, water tank, circulating pump, heat exchanger, circulating pipes, thermocouples, flow meter, etc. The water tank was just for storing the water circulated in this system. The average tank temperature was monitored by thermocouple. The radiometer, Taiwan TES1333R solar power meter, which was placed parallel to the slab surface, was used to measure the solar radiation intensity. In the test, the cold water flows out from water tank, and enters in solar collection slabs to absorb solar energy, then passes through flow meter, circulating pump, heat exchanger and finally goes back to the water tank. The heat exchanger was used for dissipating the heat absorbed by the slabs to reduce water tank temperature as much as possible. In