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REWIEW OF ROAD GEOTHERMAL SNOW-MELTING TECHNOLOGY

ВНТУ

Анотація:

В статті представлено огляди матеріалів про використання геотермічних ресурсів за регіонами світу. Показана залежність ефективності використання геотермічних ресурсів. Приведені дані, в яких країнах геотермальна енергетика розвивається найбільш успішно і для яких цілей застосовується. Розлянуто геотермальну систему танення снігу.

Ключові слова: геотермальна система, танення снігу, дороги, лід.

Abstract:

The article presents reviews of materials on the use of geothermal resources for regions of the world. The dependence of geothermal resource efficiency is shown. The data in which countries geothermal energy is developing most successfully and for what purposes are given. The geothermal snow melting system has been flooded.

Keywords: geothermal system, snow-melting, roads, ice.

1. Introduction

Nowadays, the PMMA pavement is widely used due to its advantages in summer including the good anti-skid performance and the excellent performance of chemical resistance. PMMA (polymethylmethacrylate) is a two component polymer material used in pavement construction. The addition of another component (initiator) to the resin component A results in rapid secondary crosslinking of the MMA monomer to form a high-strength coating to achieve a durable use of the road under specific conditions, which can significantly increase the performance of keeping the pavement dry and anti-skid in rainy days, and shorten the braking distance by 30-40% or more. However, the chemical PMMA pavement faces the problem of the failure of the slip resistance in winter. Because of the long winter, the long frozen period as well as the heavy snow, clearing snow has become a difficult task. Moreover, there are more traffic accidents due to the untimely snow-clearing. At present, the main method to clear snow in our country is to clear snow with mechanic equipments after using the thawing agent. The chemical compositions, such as the potassium acetate and chlorine salt in the thawing agent can cause pavement and steel corrosion. Meanwhile, the soil and water pollution, the soil salinization, the death of plants in the greenbelts as well as the serious damage to the fresh water system can be caused. There are many disadvantages of the mechanical snow removal equipments such as the uneconomical cost, the severe damage to the road surface in the process of clearing snow, the unthoroughness, and easily causing the traffic interruption.

Losses and damage caused by heavy snow are steadily increasing worldwide. Severe heavy snow paralyses national logistics systems, limiting snow removal efforts. To overcome this, many snow-melting systems have been developed; however, in practice, their application is restricted, due to economic reasons, environmental contamination, and problems and cost associated with construction technology. With respect to the treatment of the snow and ice on the pavement, researchers have conducted many studies and proposed several methods for snow-melting and skid resistance of the pavement, as shown in Figure 1. Currently, there are two major methods for melting ice and snow: snow removal with machine and snow-melting. With high efficiency, snowremoving machines are applicable for removing large area of snow and ice on pavement. However, considering the larger cohesive force between ice and pavement induced by the lower temperature, the snow-removing machine alone cannot achieve satisfactory snow removal effect and cannot thoroughly remove the ice cover on pavement.

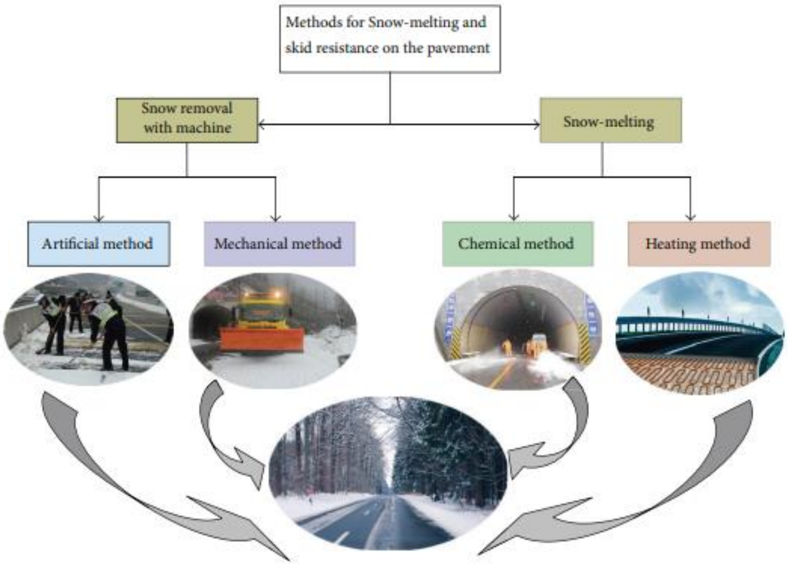


Figure 1. Methods for snow-melting and skid resistance of the pavement.

The method of heating the surface of the road to eliminate ice and snow is usually based on the use of geothermal energy and the accumulation of heat in the summer in the geothermal field. Also, the system can be supplemented with a heat pump if the energy obtained passively is insufficient. Most often, vertical soil probes are used as a geothermal field. There are also options for direct use of hot geothermal water (usually associated with special geothermal conditions) or direct use of groundwater. Another advantage of systems with a geothermal field is the removal of heat from the roadway to the geothermal field in the summer, so that it is possible to prevent overheating of the road surface.

2. Basic principles

The most common heat pumps are of the vapour compression type where a mechanically driven compressor is used as described below. When a gas is compressed without loss of heat, its temperature and pressure increase because of the work done on the gas by the compressor. Conversely, when a gas expands, its temperature and pressure decrease. Compressing and/or cooling a gas sufficiently can turn it into a liquid. Liquids and gases are separately known as states of matter and together known as fluids.

In a heat pump, a working fluid is contained in a closed, sealed circuit. The working fluid in today's geothermal heat pumps is commonly some kind of hydrofluorocarbon (HFC, chlorine free) or a natural refrigerant like propane, isobutane, ammonia or carbon dioxide. As the working fluid moves around the circuit, it is repeatedly expanded and evaporated in one part of the system, causing cooling and absorption of heat, and compressed and condensed in another part of the system, causing warming and release of heat. The effect is to move, or pump, heat from the part of the system where the fluid is vaporized to the part of the system where the fluid is condensed. Figure 2 illustrates this idea. The compressor does work on the gas, increasing its temperature and pressure.

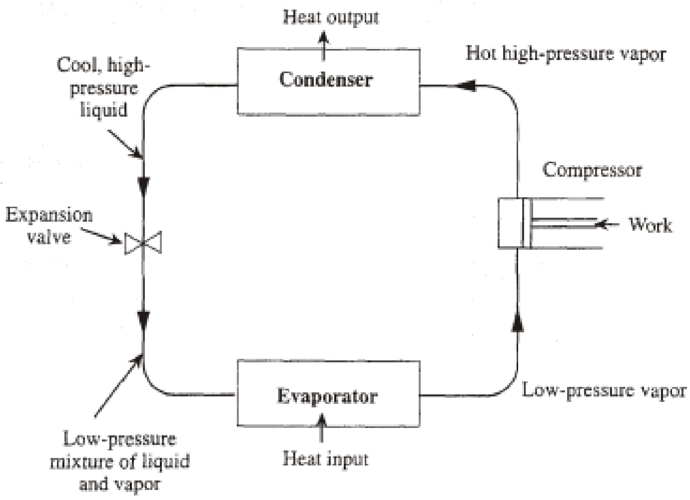


Figure 2. Schematic diagram of a heat pump (Wright, 1999)

The geothermal snow melting system consists of three parts. The first one is the snow melting equipments of the road surface, which are buried equidistantly under the road surface with L-shaped radiating pipes. The distance between the pipes is set to be 150-350mm, the depth of the buried pipes is generally set to be 50- 100mm, and the diameter of the pipes 20-35mm. The second part is the buried pipes heat exchanger. It transfers heat with the underground soil by the heat transfer fluid in the circulating water pump. The third part is the circulating water pump, which transfers the heat-transfer fluid that has exchanged heat through the circulating water pump to the radiating pipes buried beneath the road, so as to achieve the goal of melting snow. The working diagram of this system is as Figure 3.

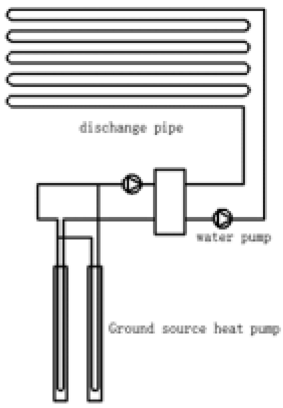


Figure 3. The geothermal snow-melting system diagram

3. Snow-melting systems examples

3.1. Iceland

In the old centre of Reykjavík, renewal of roads and pavements has been in progress since before 1990, with snow melting pipes embedded simultaneously. At present, a snow melting area of 30,000 m2 is a reality; it is expected to be extended to 60,000 m2 when renewal is complete.

In Reykjavík, geothermal hot water is used for heating houses. The distribution system is partly single pipe and partly double pipe. In the old city, a single pipe system was laid. Geothermal water, after being used for heating houses, was released into the drain system of the city. The return water, at 32/C, contains a lot of energy. While renewing the roads the opportunity for using this water in snow melting was realised. The return water is now led to five control centres for snow melting. The pipe system for the water was laid out in such a way that the centres are interconnected and the water can be distributed to the centres at will.

All snow melting pipes are plastic pipes except for the pipes in control centres, which are made of steel. Mains for supply and return water are laid from control centres and branches are connected to valve boxes where tubes are connected. All tubes are connected with valves. It is very important that these valves be easily accessible so a tube can be disconnected or relieved of air whenever needed. Therefore, concrete valve boxes with cast iron cover plates at final surface level have been used (Figure 4). Thus, access to valves is possible without removing stones from the slab.

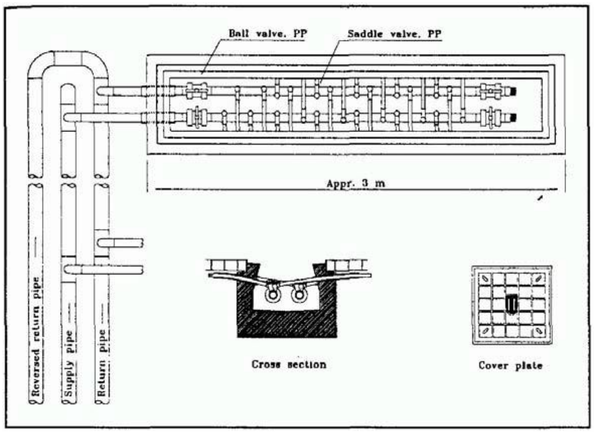


Figure 4. Valve box in a snow melting system in Iceland (Ragnarsson, 1997)

The pipe system is a reverse-return system that maintains pressure balance. All snow melting tubes are of equal length, 280 m. The distance between pipes is 0.25 m. Special requirements for more snow melting are met with less distance between pipes, 0.2 m. Tubes are embedded in special sand underneath a stone slab. The sand has higher heat conductivity than ordinary sand. In roads with heavy traffic load from buses, pipes are laid in the asphalt layer (Ragnarsson, 1997).

3.2 Japan

In the Gaia snow-melting system, the Downhole Coaxial Heat Exchanger (DCHE) is used for extracting heat from the earth. The heat exchanger uses a thermally insulated inner pipe and reverse circulation, i.e. the cold fluid flows down the annulus and warmer fluid flows up through the inner pipe, for efficient heat extraction.

The first Gaia snow-melting system was installed in Ninohe, Iwate Prefecture, a city 500 km north of Tokyo, and has been operating successfully since December 1995. The average low temperature for the month of January is -7.1/C. Annual snowfall in the winter of 1995/96 was 2.9 m. The Gaia system was installed at the downhill section of a curved road with a 9% gradient, in order to prevent accidents by skidding and sliding vehicles in winter. The area covered by the snow-melting system is 4 m wide and 65 m long, covering a total area of 266 m2. Heating pipes were embedded in the asphalt concrete pavement at 10 cm depth and 20 cm intervals. The material under the road consists of sandy rock and the undisturbed temperature is 22.5/C at a depth of 150 m. Three DCHEs, each 8.9 cm in outer diameter and 150 m deep, and a 15 kW (electric) heat pump were used. In winter, heat extracted from the earth by DCHEs is transferred to a heat pump. After the temperature is increased by the heat pump, the thermal energy is transmitted to a heating fluid circulating through a network of heating pipes, which melt the snow (as shown in Figure 5). Antifreeze is used as both a heat extraction medium and a heating medium.

In summer, solar heat raises the temperature of the road in which the heating pipes are embedded, up to 30-50/C. The solar heat is recovered from the road and stored in the earth by connecting the DCHEs and heating pipes directly, and by circulating the fluid in this loop. The warmed fluid in the heating pipes flows into the DCHEs and warms up the surrounding earth, thereby storing the solar heat in the earth. In this way, summertime solar heat is stored for use in the winter for melting snow. This heat storage operation is controlled automatically by referring to the temperatures of the fluid at the bottom, inlet and outlet of DCHEs as well as the road. The Gaia system in Ninohe City demonstrated a reduction of 84% in annual energy consumption compared with systems in Ninohe which use electric heating cables (Morita and Tago, 2000).

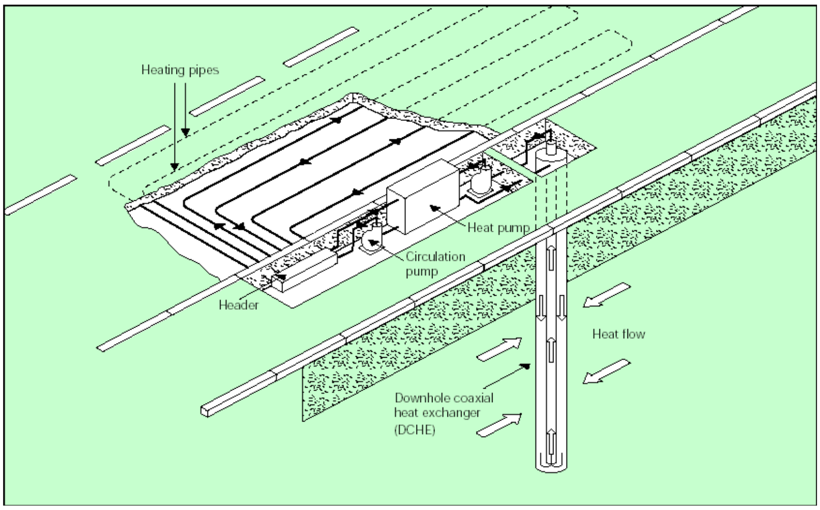


Figure 5. Layout of a snow melting system in Japan (Caddet, 2003)

3.3. United States

The oldest geothermal pavement snow-melting system was installed in Klamath Falls, Oregon, in 1948 by the Oregon Highway Department. This is a 450' long section of Esplanade Street approaching a traffic signal on an 8% grade. The grid consisted of ¾" diameter iron pipes placed 3" below the surface of the concrete pavement on 18" centres. The grid system was connected to a geothermal well with the heat transferred through a downhole heat exchanger to a 50-50 ethylene glycol-water solution that circulated at 50 gpm.

By 1997, after almost 50 years of operation, the system failed due to leaks in the grid caused by external corrosion. In the fall of 1998, a contract was issued to reconstruct the bridge deck and highway pavement along with replacing the grid heating system. The top layer of concrete on the bridge deck was removed by hydroblastin and the roadway pavement was entirely removed, and a new crushed rock base added. A ¾" cross-linked polyethylene tubing (PEX) was then used for the grid section, placed in a double overlap pattern resulting in line spacing from 14 to 16" on centre (Figure 6). The PEX pipe was attached to the reinforcing steel within the concrete pavement, providing a cover of about 3" over the pipe within the 7" pavement section. The header pipe, placed along the edge of the roadway consisted of 1.25-2.5" insulated black iron pipe, which in turn was connected to the downhole heat exchanger. The header pipe had brass manifolds placed at about 40' intervals in concrete boxes, to allow for four supply and return PEX pipes to be attached (Lund, 1999).

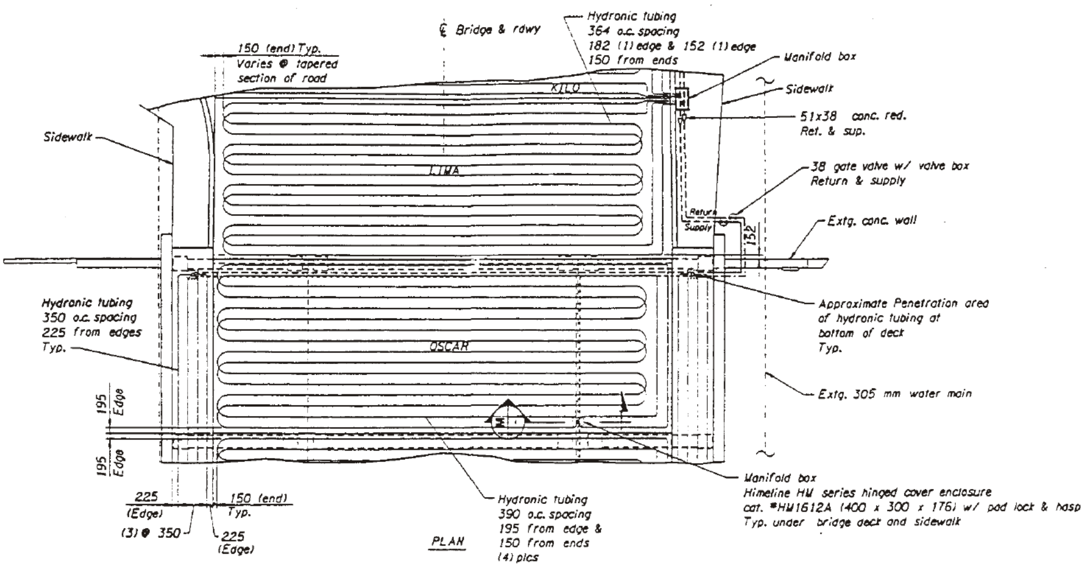


Figure 6. Details of a snow melting installation in Klamath Falls, USA (Lund, 1999)

Conclusions

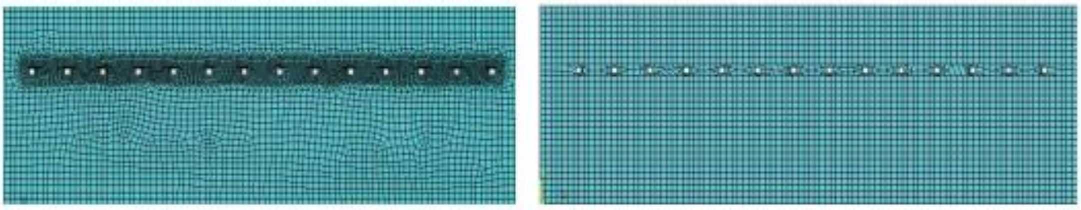
Considering the limitations of present antiskid measures adopted by highway maintenance division and the extensive Advances in Materials Science and Engineering applications of electric heat tracing system, the snow-melting heated pavement system in tunnel portal was proposed. Based on field experiment, laboratory experiment, and numerical investigation, conclusions may be summarized as follows:

(1) In cold region, the electric heat tracing system can be employed for the snow-melting of the pavement in tunnel portal. In order to realize instant and automatic melting, it is required to preheat the pavement according to the actual weather conditions.

(2) Considering the air temperature, vehicle emergency braking distance, and “snow scarp” effect, the optimum longitudinal length of the pavement with electric heat tracing system should be 50 m inside the tunnel and 50 m outside the tunnel.

(3) In order to effectively improve the heating efficiency, thermal insulation materials can be laid below the heating cables. Combined with thermal insulation materials, the electric heat tracing system with heating power of 200–400 W/m2 can sufficiently meet the requirements of pavement snow-melting when the air temperature is −20–0◦ C.

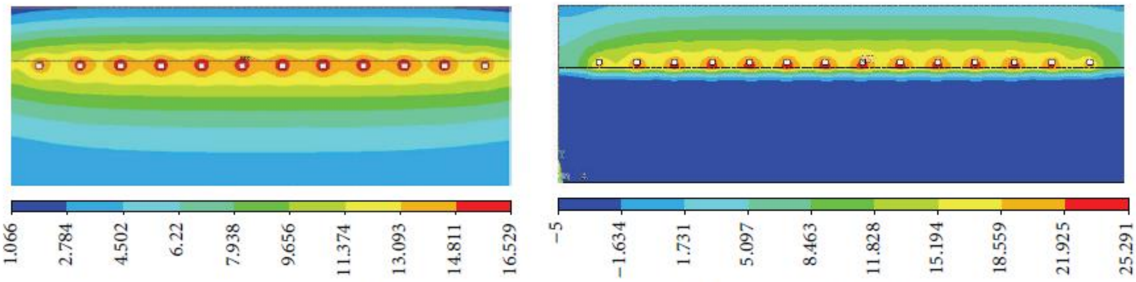
(4) Based on field experiment and laboratory experiment, the numerical investigation can systematically analyze the temperature field distribution of the snow-melting heated pavement system, which truthfully reflects the temperature distribution of the pavement structure.



(a) Calculation model of the pavement without thermal insulation layer

(b) Calculation model of the pavement with thermal insulation layer

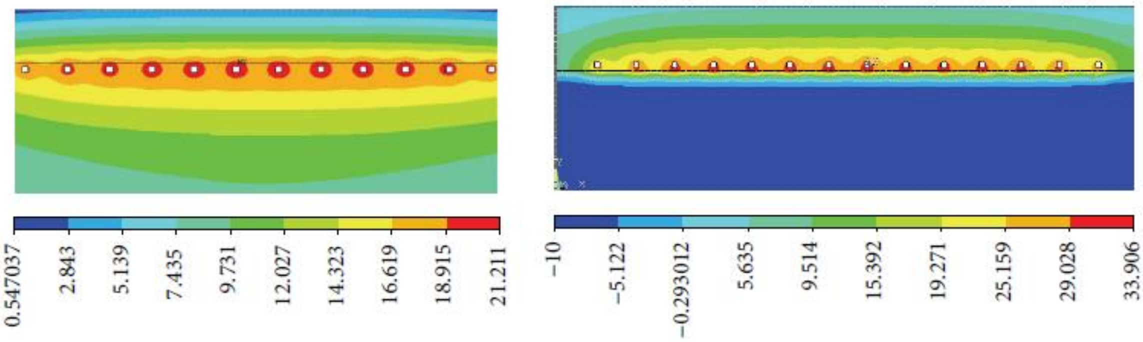
Figure 7: Calculation model of the pavement.



(a) Heating effect without thermal insulation layer

(b) Heating effect with thermal insulation layer

Figure 8: Temperature field distributions with heating time of 5 hours and air temperature of −5∘C.



(a) Heating effect without thermal insulation layer

(b) Heating effect with thermal insulation layer

Figure 9: Temperature field distributions with heating time of 10 hours and air temperature of −10∘C.

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