An experimental study of permafrost restoration under the seismic line in the wetland-dominated zone of discontinuous permafrost, Northwest Territories, Canada

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ABSTRACT

Thermosyphons are closed-system heat extraction devices. They extract heat from the ground, contributing to cooling of frozen ground and maintaining temperature below zero and as such are useful for preserving permafrost. Two types of thermosyphons are used: passive and hybrid systems. Passive one does not require any external power to operate. The hybrid installation combines the passive system with a refrigeration compressor so that negative soil temperatures are maintained during summer. The most common type of thermosyphon uses a carbon dioxide filled vessel under a pressure varying from about 2100 to 4800 kPa. Thermosyphon technology is successfully used for stabilizing building foundations, dams and pipelines. While passive thermosyphons do not require extensive maintenance they do require specially trained personal for installation. Also the high cost of thermosyphons limit their extensive use below linear infrastructure. Liquid based thermosyphons were developed and tested as an inexpensive alternative to carbon dioxide system. This paper presents and discussed the technical aspects of liquid-filled thermosyphons and demonstrates their application in a region of degrading permafrost at Scotty creek, NW, Canada.

Key words: Seismic line, permafrost, thermosyphons.
INTRODUCTION

Surface disturbance of ice rich soils in permafrost regions results in permafrost degradation, reduction of ground bearing capacity and slope stability problems. Preventing permafrost thaw is a serious concern for the construction industry. One of the most popular methods of maintaining permafrost in its natural state is the use of thermosyphons. Thermosyphons have been used for stabilizing foundations in continuous and discontinuous permafrost areas since 1960 Richardson, (1979). There are two types of thermosyphons: passive and hybrid Johnston, (1981). Passive thermosyphons contain no moving parts. These sealed pipes are usually filled with carbon dioxide at a high pressure of 2-5 MPa. Pipe pressure should be adjusted during installation to ensure that carbon dioxide located below ground is maintained in liquid form. Vaporization of the liquid carbon dioxide results in a heat transfer from the lower part, the evaporator, of the thermosyphon to the upper part, the condenser, where it condenses in winter time and trickles back down to the evaporator. Passive thermosyphons work only in the winter time and remain dormant while the air temperature is higher than the ground temperature. Hybrid thermosyphons are designed to keep the ground frozen in the summer as well as the winter time, but this process involves an active refrigeration system. A comprehensive analysis of thermosyphons or heat pipe application for ground stabilization under prolonged linear infrastructure such as the Alaska Pipeline, was done by Heuer, (1979) for the U.S. Army Cold Regions Research and Engineering Laboratory. Another detailed study of building support provided by thermosyphon technology was conducted by Holubec (2008) for the Government of the NT Asset Management Division Public Works and Services. Both studies described two-phase thermosyphons. In the Alaska Pipeline case, only passive thermosyphons were used, while projects in Northwest Territories employed passive as well as hybrid thermosyphon technology. While ground freezing with thermosyphons can be considered as a "last line of defence" when any other methods for foundation stabilization are not available or are not feasible due to geotechnical conditions or high costs, this technology is nonetheless very expensive. According to the Government of the Northwest Territories, Department of Transportation, climate change may affect the quality of Highway 3, the main highway of the NWT, which is already under extensive maintenance every summer. However, thermosyphon technology is not applied in this case because of associated costs, among other factors. The complex installation process of thermosyphons is another factor which limits their use. Heuer, (1979) noted that installation of heat pipes affects construction timing, as it requires special knowledge and skills, which are often not available within general drilling contractor crews. Thermosyphons are an effective, but expensive technology for the prevention of permafrost thaw. The cost of this technology limits its application under linear structures such as roads. In some cases, it is more prudent to invest in road maintenance, rather than the prevention of permafrost thaw.

SITE LOCATION

The Scotty Creek basin is located approximately 50 km SE of Fort Simpson, NT. (Figure 1)

The average annual temperature in the region is -3.2°C (1964-2013). The average temperatures for July and January are 17.1°C and -25.9°C, respectively. This area belongs to the continental climate zone and is situated in the region of discontinuous permafrost. The installation was done in a highly disturbed area of the 1985 seismic line. The removal of vegetation and soil compaction at this seismic line led to the loss of ~ 2.5 m of permafrost during last 30 years. The Active layer, the seasonally frozen layer, at the experimental site varies from 50 to 60 cm, the thickness of talik, the perennially unfrozen layer, is about 2 m. The thawing of permafrost created a visible channel through the peat plateau, with a depth of which is about 1-2 meters. The soil layer of interest is 100% saturated peat with a porosity of ~ 80%. The testing of performance was done during the winter of 2016-2017. The test site was equipped with temperature monitoring stations in August 2014.

DESCRIPTION AND PRINCIPALS OF OPERATION

The proposed thermosyphon (Figure 2.) consists of a heat exchanger (1), submersible pump (2), and two coaxial pipes: external (3) and internal (4). The external pipe is connected to the heat exchanger and is sealed at the bottom and filled with any antifreeze mixture or coolant such as ethylene glycol, methanol, etc. The submersible pump operates on any source of renewable energy (5) such as a solar panel, wind powered generator, etc. Additionally, the submersible pump can also be connected to a battery (7). The submersible pump is operated through a thermal switch (6), which stays opened when the temperature is above 0°C and closed when
temperature drops below $0 ^\circ C$. The proposed thermosyphon can be installed in the permafrost layer (III), or just above it in the perennially unfrozen layer, talik (II). The aboveground portion of the thermosyphon should be higher than the maximum anticipated snow depth in the area of installation. The submersible pump can be connected to the top of the internal pipe: case A, or to the bottom of the internal pipe case B.

Figure 2: The proposed thermosyphon consists of a heat exchanger (1), submersible pump (2), and two coaxial pipes: external (3) and internal (4).

When the air temperature drops below $0 ^\circ C$, the thermal switch closes and the submersible pump circulates the coolant inside the thermosyphon. Exposed to the freezing temperatures above ground, the stream of cold fluid descends (case A) through the internal pipe, displacing warmer fluid at the bottom of the external pipe, forcing it to ascend into the heat exchanger, where it cools down through the process of heat radiation. If the submersible pump is connected to the bottom of the internal pipe, as in Case B, the stream of warmer fluid from below ground ascends into the heat exchanger through the internal pipe, displacing colder fluid from above ground and forcing it to descend and absorb heat from the ground, thus cooling it. In both Cases A and B, the circulation of coolant through the coaxial pipe creates a heat pump effect, which cools the subsurface environment, thus preventing further thaw and promoting permafrost regeneration.

4 RESULTS

Both cases were tested. Case B was tested with a solar panel backed up with a 12V car battery; case A was tested with just a solar panel. The external aluminum pipe had a length of 3 m and a diameter of 75 mm. The maximum snow thickness for the experiment was ~50 cm. Thus, only 50 cm of the thermosyphon was exposed to open air. The thermosyphon was equipped with a low power consumption (0.8 W) submersible pump to circulate the coolant. The outflow from the submersible pump was directed through 12.5 mm pipe to the bottom (case A) or the top (case B) of the thermosyphon. The operational rate of the pump was between 40 and 120 L hr$^{-1}$, depending on the performance of the solar panel. As a heat exchanger a 6 mm copper coil was installed in the upper part of thermosyphon to reinforce the cooling process (Case B). In Case A the top of the aluminum pipe acted as the heat exchanger. The power line was equipped with a mechanical thermal switch, which connected the power supply to the pump when air temperatures dropped below zero. Four thermistors were placed around the thermosyphon at various distances and depths (Table 1, Figure 3). An additional thermistor was placed close to the bottom of the thermosyphon at a depth of 199 cm.

<table>
<thead>
<tr>
<th>Thermistor #</th>
<th>Distance cm</th>
<th>Depth of thermistor installation, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4</td>
<td>16.6</td>
<td>181</td>
</tr>
<tr>
<td>T5</td>
<td>24.8</td>
<td>199</td>
</tr>
<tr>
<td>T7</td>
<td>20.5</td>
<td>155</td>
</tr>
<tr>
<td>T8</td>
<td>17.3</td>
<td>203</td>
</tr>
</tbody>
</table>

Table 1. Thermistors locations. Distances are from exterior wall of the thermosyphon.

Figure 3. Four thermistor’s locations (# 8,4,7,5) around thermosyphon #5

Figure 4 demonstrates test results for Case B.
As shown in Figure 4, the soil in close proximity of the thermosyphon was frozen to an average temperature of ~ -3°C. Radius of freezing reached ~ 20 cm with average temperature ~-0.5°C. Limited data is available for Case A (Figure 5).

The submersible pump was placed in the above ground section of the thermosyphon and powered solely from a solar panel. In this setup, a 0.8 W pump and a 20 W solar panel were used. The pump operated even under a cloudy sky without direct sunlight. The diurnal cycle is reflected in a slight increase in nightly temperatures, with a general trend of temperature decrease.

5 CONCLUSIONS

This paper presents the results of an experimental study of liquid filled thermosyphons with forced circulation. With recent developments in energy-conserving technologies and renewable energy sources, the system presented here is an economically feasible alternative to traditional two phase passive thermosyphons. According to data obtained from the field experiment, the proposed thermosyphon can transfer sufficient thermal energy to freeze the saturated peat layer within a diameter of at least 50 cm around, even with a relatively short above-ground section. The low power consumption submersible pump can maintain a below 0°C temperature in the frozen layer throughout the cold season, while operating exclusively on a renewable energy source, such as a solar panel or a small wind turbine generator.

Data obtained from field experiments shows that even with a relatively short above-ground section, which is exposed to cold air, the proposed thermosyphon can transfer sufficient thermal energy to freeze the saturated peat layer at a diameter of at least 0.4 m around a 3 inch thermosyphon. The low power consumption submersible pump can be operated exclusively on a renewable power source, such as a solar panel or small wind turbine generator in order to maintain below 0°C temperatures in the frozen layer throughout the cold season. It should be noted that only one thermosyphon was tested in this experiment. A cluster of thermosyphons can be expected to yield much better result.

The content of this paper has patent pending status

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