SNOW MELTING PERFORMANCE OF GROUND SNOW MELTING TANK

S. Takeda, K. Nagano, T. Katsura, T. Ibamoto, S. Narita

Hokkaido University
Sapporo, 060-8628 Japan
Tel: +81-11-706-7597
sayakat@eng.hokudai.ac.jp

Y. Nakamura

Nippon Steel Corporation
Tokyo, 100-8071 Japan

1. INTRODUCTION

The city of Sapporo is located in the northern part of Japan and has a lot of snow over 5 m high every year. The city government then makes a budget for snow control measures, which reaches more than 125 million USD per year recently [City of Sapporo, 2006]. Removed snow from the road ways is generally transported by trucks to temporary dumping sites in the suburbs. The transport needs huge costs around 30% of the budget and may cause increase of CO$_2$ emissions. Therefore it is important to pay attention to onsite snow removal measures now, which are expected to be both low cost and environment-friendly.

The authors have proposed the Ground Snow Melting Tank (GSMT) made of large hollow steel piles, in which ground thermal energy is utilized directly for snow melting without the use of fossil energy resources. A conceptual diagram is shown in Figure 1. The use of steel piles makes it relatively easy to construct a large underground space even in the urban area. In particular, processing performance will be increased with an increase of the diameter of a pile.

In this study, the effect of rotating movement of water in the GSMT is examined in laboratory experiments as a means of improving the snow melting performance. This study also reports field experiments conducted in the Hokkaido district in the winter season of 2005-2006 with a GSMT of 16.3 m long and a diameter of 1200 mm.$\phi$. Snow melting performance is evaluated quantitatively by the experiments, in which snow is shoveled periodically by a snow blower simulated an actual use and nearly filled in the GSMT throughout the experiments. The snow melting performance is compared to calculations by a theoretical analysis which gives maximum performance. Finally feasibility of the GSMT for road ways or residential area is discussed by using the

Figure 1 Conceptual diagram of the GSMT
2. LABORATORY EXPERIMENT ON INCREASE OF SNOW MELTING PERFORMANCE

2.1 Experimental setup

We performed laboratory experiments to verify that snow melting performance is increased by rotating movement of water in the GSMT. Shown in Figure 2 is a schematic diagram of the setup. The GSMT is simulated by a cylinder made of acrylic resin, which is 100 mm in diameter and 1.5 m in height. A nozzle installed at the bottom supplies water at a constant temperature to the cylinder. The nozzle is fixed at an angle of 45º to the side wall and one of 30 ºC to the bottom. The water rotates in the cylinder during snow melting and is discharged from an outlet to keep at a constant level. Water level can be chosen at 300 mm intervals from 300 mm to 1200 mm from the bottom.

2.2 Experimental conditions

Two kinds of nozzles, which diameters are 8 mm and 4 mm, were applied in the experiment. The water level was set at 0.6 m or 0.3 m from the bottom. Water flow rate was varied between 2 L/min and 6 L/min and was measured by a magnetic flowmeter. Supplied water temperature was controlled at 5 ºC by a constant temperature water bath. Room temperature was around 18.0 ºC during the experiments.

Fresh snow of 500 g was put into the cylinder from above at the start of one experiment, causing rotating movement of water. The snow was collected in an insulated box in advance. The density of the snow was approximately 180 kg/m$^3$. Snow melting performance is calculated by using the measured time until the snow melts completely.

2.3 Results and discussion

The left picture of Figure 3 demonstrates a state of snow melting in the cylinder. Relationships between water flow rate and snow melting performance in each case are shown in Figure 4. Higher variations of snow melting performance are observed in the conditions with the nozzle of 4 mm than those of 8 mm owing to increase of outlet velocity from the nozzle. For example, snow melting performance in the condition with the 4 mm nozzle is 552 W and 44% higher than that in the condition with the 8 mm nozzle at a water level of 0.6 m and a flow rate of 4 L/min.

Similarly the conditions with the lower water level at 0.3 m result in higher snow melting performance than those with the water level at 0.6 m in each nozzle case. For instance, the snow melting performance in the conditions with a water level of 0.3 m achieves about 1.9 times higher than that in the conditions with a water level of 0.6 m in the both nozzles at a flow rate of 4 L/min in these experiments.

Here, thrown snow was observed visually to melt under the effect of water moving at a water level of 0.3 m, while snow is not able to reach the lower area than 0.3 m high from the bottom in the conditions with a water level of 0.6 m. The
difference is probably due to differences of water resistance on the wall surface to the rotating movement relatively.

Moving area of water in the cylinder is distinguished by a doppler ultrasonic flow meter made by Nortek AS as shown in the right figure of Figure 3, in which three-dimensional flow direction and velocity of water are observed [Nortek AS, 2006]. Measured moving and non-moving areas in the conditions with a water level of 0.6 m and the nozzle of 4 mm or 8 mm are shown in Figure 5. The results show that moving area of water in the cylinder is increased as the size of the nozzle gets smaller or flow rate increases. The condition with the 4 mm nozzle shows a 1.8 times larger moving area than that with the 8 mm nozzle at a flow rate of 4 L/min. No moving can be observed at higher than 0.3 m from the bottom in both nozzles in these experiments. This seems to lead to the increase of snow melting performance in the conditions with a water level of 0.3 m above mentioned.

![Image](image_url)

**Figure 4 Snow melting performance in each condition**

**Figure 5 Moving and non-moving areas in the cylinder measured by doppler ultrasonic flow meter**

### 3. SNOW MELTING PERFORMANCE IN FIELD EXPERIMENT

#### 3.1 Outline of the experiment

Field experiments are conducted in Ishikari city in the Hokkaido district shown in Figure 6 in the winter season of 2005-2006 with a GSMT of 16.3 m long and a diameter of 1200 mm. Installation of the GSMT is shown in Figure 7. A well pump is installed in a polyvinyl-chloride pipe of 100 mm on the inner wall. The pump can provide water moving around the bottom of the GSMT as well as discharge water to the outside by change of piping on the ground.

Figure 8 shows the result of a geological survey at the site. The soil mainly consists of fine sand around the area of the GSMT. There is ground water below 2.6 m from the ground level, but ground water flow cannot be observed. Effective ground thermal conductivity of this site is evaluated to be 1.6 W/m/K by the thermal response test conducted by using a well of 120 mm for the ground survey.

![Image](image_url)

**Figure 6 Site of field experiment**

**Figure 7 Construction of GSMT using a rotating press-in steel pile**

**Figure 8 Geological composition**
3.2 Possible amount of snow to throw in the GSMT

Firstly, possible amount of snow to throw in the GSMT is measured, with moving water below 3.2 m from the bottom of the GSMT. Snow put into a bag by a shovel was hung by a crane and measured the weight by a digital scale and then thrown into the GSMT as shown in Figure 9. The process was repeated until the GSMT is filled by snow.

Totally 5.3 tons of snow can be put into the GSMT. The amount is equivalent to 22.4 m$^3$ by volume since the average density of the snow is estimated around 237 kg/m$^3$. This volume is 1.6 times larger than the vacant air volume above the initial water level of 13.7 m$^3$. On the other hand, a similar measurement with another GSMT of 800 mmφ also allows nearly equal amount of snow to throw in it even though no means were done during the throwing. Therefore, this experiment was not able to bring about obvious effect of snow melting by moving water in the GSMT. This is probably due to a large amount of thrown snow relative to the amount of water in the GSMT, differed from the laboratory experiments in which a small amount of fresh snow is thrown in the cylinder. In such cases, showering from the top of the GSMT with pumping from the bottom is a possible means to increase of the snow melting performance in the near future.

3.3 Maximum snow melting performance through periodical charge

3.3.1 Experimental conditions

Next, the maximum snow melting performance is evaluated by periodical shoveling to the GSMT. Snow is shoveled every 3 to 4 days periodically by a snow blower as shown in Figure 10 and nearly filled in the GSMT throughout the experiment as indicated in the top of Figure 12. The density of shoveled snow is 474 kg/m$^3$ on average. In seven times of the first half, shoveling is carried out with water moving in the GSMT. Water in the GSMT is pumped out by the well pump before each snow shoveling to keep the water level at 3 m high from the bottom as shown in Figure 12. Snow melting performance is then evaluated by the volume of the discharging water.

3.3.2 Results and discussion
The second and third graphs of Figure 11 show average snow melting performance per the surface area of the GSMT and integrated amount of snow melting. Snow melting performance reaches around 50 W/m² until the second shoveling, while it decreases with time after that and becomes about 12 W/m² after 41 days. Integrated amount of snow melting increases to 12.7 tons at that time.

3.4 Comparison to theoretical analysis

Heat flux through the soil from infinite distance to the surface of the GSMT is calculated by a theoretical analysis. The analysis regards the GSMT as an infinite cylinder and gives a boundary condition of heat transfer at 0°C at the surface of the cylinder [Carslaw, 1959]. The heat from the soil is considered latent heat for snow melting in the GSMT in the analysis. Therefore, the analysis gives us the maximum performance of snow melting in the GSMT.

Specification of the analysis is as follows. Effective thermal conductivity is given as 1.6 W/m/K from the thermal response test above mentioned. Thermal capacity of the soil is 3,000 kJ/m³/K and the initial ground temperature is 9.5°C. Specification of the GSMT is the same as that in the field experiment, that is, a diameter of 1200 mmφ and a length of 16.3 m. The analysis doesn’t deal with the influence of the ground water flow and vertical heat transfer.

Figure 11 also compares the calculated snow melting performance and integrated amount of snow melting to the experiments. The calculation can reproduce the tendencies of the experiment in both variations. The difference of the amount of snow melting is only 1% between the calculation and the experiment after 41 days at the end of the experiment. This result means that the GSMT filled by snow throughout the measurement shows nearly maximum performance of snow melting. Moreover, this theoretical method can be utilized for evaluation of performance of the GSMT in such conditions.
4. APPLICATION OF GSMT TO ROADS AND RESIDENTIAL AREA

4.1 Input conditions

Here, feasibility of the GSMT for roadways and residential area is discussed by using the theoretical analysis. The length of the GSMT is regarded as 30 m supposing an actual use. The same values as the above calculation are used about the effective thermal conductivity, the thermal capacity and the diameter of the GSMT. 10ºC and 13ºC are given as infinite ground temperatures equivalent to cities in the cold region and semi-cold region in Japan. In the use of multiple GSMTs, supposing that performance of snow melting is increased in proportion to the number of the GSMT. Also, multiple GSMTs are then installed at suitable intervals so as not to be influenced by thermal interference each other.

Shown in Figure 12 is a cleared width on a roadway near a crossing. Table 1 also indicates cleared area of 2, 4 and 6-lane roadways per one corner given in the calculation. For instance, about a 4-lane road, the width of one side of the road is 6 m and the edge is 0.5 m. Supposing that 85% of the summation, 5.5 m, and a length of 50 m from the crossing should be cleared, the area is then estimated to be 276 m².

Figure 13 shows a cleared area in residential houses. The area is calculated to be 45 m² per one car parking and one sidewalk around a house. Suppose that the density of fresh snow is 80 kg/m³ and the annual height of snowfall is 5 m in total.

4.2 Results and discussion

Figure 14 indicates relationships between the number of GSMT and the total amount of snow melting in a winter season. It is found that the amount of snow melting is increased with the difference between the initial ground temperature, 10 ºC or 13 ºC, and the surface temperature on the GSMT, 0 ºC. The cases at ground temperature of 13ºC show 1.3 times larger performance than those at the other temperature of 10 ºC in these calculations. The figures also show the number of the GSMT needed in the roadways and the residential houses against the amount of snow to be cleared. For instance, it can be seen that two GSMTs are needed for one corner of a 4-lane roadway in the case of ground temperature of 10 ºC. Similarly in the residential houses, the amount of snow to be cleared from 6 houses is equivalent to snow melting performance of two GSMTs with 30 m long. Thus, these diagrams can explain how many GSMTs are needed in actual uses and possibility of the GSMT as an onsite snow melting tank.
5. CONCLUSIONS

The following summarizes the results reported in this paper.

1) Laboratory experiments intended to improve the snow melting performance in the Ground Snow Melting Tank (GSMT) are conducted with a cylindrical pipe of 100 mm $\phi$. Water supplied from a nozzle on the bottom of the cylinder causes rotating movement under appropriate conditions. The water movement can be observed in the cylinder below 0.3 m high from the bottom in the experiments. It is found that the water movement is effective to improve the snow melting performance against a small amount of snow.

2) Field experiments are conducted with a GSMT of 1200 mm $\phi$ and 16.3 m long in order to evaluate the maximum performance of snow melting. The snow melting performance is confirmed quantitatively by the experiments, in which snow is shoveled every 3 to 4 days periodically and nearly filled in the GSMT during the experiment. The result shows that the maximum performance of snow melting is around 13 tons for 41 days.
3) The performance on snow melting measured in the experiments agreed well with results from a theoretical calculation which shows the maximum performance. This theoretical method can be utilized for evaluation of performance of the GSMT in case where snow is filled in the GSMT throughout the period.

4) Feasibility of the GSMT for roadways and residential houses is investigated by using the theoretical calculation. It predicts that the amount of snow to be cleared from one corner of a two-lane roadway or six residential houses can be melted by two GSMTs with 30 m long and a diameter of 1200 mmφ when the initial ground temperature is 10ºC and the seasonal snowfall is 5 m high.

REFERENCES

