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Snow storage – Modelling, theory and some new research

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ABSTRACT

The arrival of natural snow is often delayed nowadays due to global warming. This causes problems for ski resorts and other places where winter activities in different forms take place. Storing snow provides one solution for the winter business industry to deal with this problem. However, there is so far very little research concerning this question. In this paper a review of current knowledge of snow storage and experiences from mainly Scandinavian snow storages is presented. New results concerning melting losses of stored snow from a trial experiment in the north of Sweden are presented. These results are compared to theoretical calculations. The model used for the calculations is shown to be useful for estimating melting losses of insulated piles of snow. Thus the calculations can serve as an important background when designing an insulated snow depot. The model can also be used to compare different insulating materials and to determine properties such as thickness of the insulating layer needed to sufficiently insulate the snow. By minimizing the surface area of insulated snow depots, melt rate due to heat from the air, sun and sky, which constitute the largest part of the total melt, can be reduced. The quality of insulating materials used will be subject to annual observation. Commonly used insulating materials such as bark, wood chips, cutter shavings and sawdust deteriorate.

1. Introduction

Storage of snow is an old technique which was common for food storage applications before refrigerators were developed at the beginning of the 20th century (Skogsberg, 2005). Skogsberg and Nordell (2001) mention for instance himuros and yukimoros, which are houses or rooms where vegetables are stored together with ice or snow in order to maintain their quality. Nowadays snow and ice are stored for different purposes. Japan, China, Canada, USA and Sweden are some countries where different techniques of snow and ice storage for cooling applications have been performed (Nordell and Skogsberg, 2007; Kumar et al., 2016). The hospital in Sundsvall, Sweden, is one example where snow has been stored for cooling purposes (Skogsberg, 2001). Utilizing snow and ice for cooling is according to Nordell and Skogsberg (2007) a renewable natural energy without any environmental drawbacks.

An enhanced interest in storing snow for winter activities has been observed during the last decade. Due to global warming, the arrival of natural snow has become more unpredictable and at the same time higher temperatures imply difficulties with traditional snow making. Storing snow in order to guarantee an early start of the season has become more common for establishing cross country ski tracks, alpine ski slopes and ski jumping areas. A stored snow depot enables resorts and skiing facilities to guarantee a fixed opening date. Stored snow is also used for summer ski events. The typical size for a snow depot is 5000–30,000 m^3, although they may also be larger (Martikainen, 2016). According to Martikainen (2016) the first insulated snow storage in the world specifically for skiing was located in Ruka, Finland in 2000. Different types of insulating materials, such as sawdust, foamed plastics, aluminum foil, geotextiles and sheets with different properties have been used to insulate stored snow. Both natural and machine-made snow can be stored, although machine-made snow is more common when storing snow for winter activities since it is considered more durable and weather resistant than natural snow (Rixen et al., 2003, 2004 and others).

Snow can be stored indoors in a thermally insulated building, underground in a cavern in which case no insulation is necessary, or on the ground in open ponds or pits. Snow stored on the ground covered with some kind of insulating material is the most common method (Nordell and Skogsberg, 2007). The thermal insulating material can be either natural materials or fabricated materials. There are different methods for insulating open pond snow storages, i.e. piles of snow which are stored on the ground. Martikainen (2016) distinguishes between three different methods; a breathable method, which means an insulating material which enables evaporation, a non-breathable method, which is an insulating material which only insulates the snow, or a combination of the two methods. Most common in Scandinavia seems to be a breathable method with a natural insulating material.

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Table 1
Places where snow has been stored, the approximate volume, insulating materials used and estimated volumes of snow melt (Ädel, 2012; Pelkonen, 2013; Hedlund, 2016; Martikainen, 2016; Rindal, 2016; Rommedahl, 2016).

Place	Volume [m^3]	Cover material	Estimated total snow melt[%]
Vuokatti, Finland	20,000–25,000	Tarpaulin and Sawdust, 30–40 cm	20
Östersund, Sweden (2006)	2 piles – 10,000	Sawdust, ≈70–80 cm	30
Östersund, Sweden	20,000	Sawdust, ≈50 cm	20
Östersund, Sweden (2015)	30,000	Sawdust, ≈40 cm	12
Orsa, Sweden	5000	Bark, ≈40–50 cm	–
Högbo Bruk, Sweden	8000	Sawdust	–
Piteå, Sweden (2012)	2400	Geotextile, Bark, ≈50–70 cm, partly covered with plastics	29
Piteå, Sweden (2013)	3400	Geotextile and Bark, ≈50–60 cm	29
Arjeplog, Sweden (2013)	1600	Geotextile and Bark, ≈40–50 cm	61
Sochi, Russia (2013)	800,000 (several piles)	Geotextile in several layers, foamed plastics, aluminum foil	20–50
Birkebeiner Ski Stadium, Norway	40,000	Wood chips, ≈30–50 cm	ca. 17

Fig. 1. Snow storage (about 25,000 m^3) insulated with sawdust, Vuokatti, Finland, 2013.

Table 1 shows a compilation of information from some places where snow has been stored together with the insulating materials used. Natural insulating materials are, for example, bark, crop residues such as rice husks, mineral particles or debris and different types of wood chips, which here include cutter shavings of different sizes, sawdust and wood powder. Fabricated materials are generally different kinds of loose sheets, such as plastic sheets, filled tarpaulins (e.g. with straw), geotextile sheets, aluminum foil, felts and sometimes thermal foam in between (Skogsberg, 2005; Martikainen, 2016). The most commonly used insulating materials for snow storages in Scandinavia are bark and different types of cutter shavings. As an example, a pile of stored snow covered with sawdust is shown in Fig. 1.

According to Martikainen (2016) a snow depot should be associated both with low environmental impact and snow available at a low cost. Therefore, many local factors at the place where the snow is supposed to be stored need to be taken into account in order to optimize the snow depot.

There are many different factors which affect the melting rate of an insulated snow depot. Skogsberg (2005) categorises snow melting in warm surroundings as natural melt and divides it into three parts; ground melt, surface melt and rain melt, see Fig. 2. Ground melt is due to heat transfer through the bottom of a pile placed on the ground. Surface melt occurs by heat transfer from the air, sun and sky. Rain melt is melting caused by rain seeping through the insulation to the snow. Surface melt is, according to Skogsberg (2005), the major factor influencing the total melt rate. The climate, the choice of thermal insulation and the geometry of the snow pile are factors affecting the melting rate (Nordell and Skogsberg, 2002).

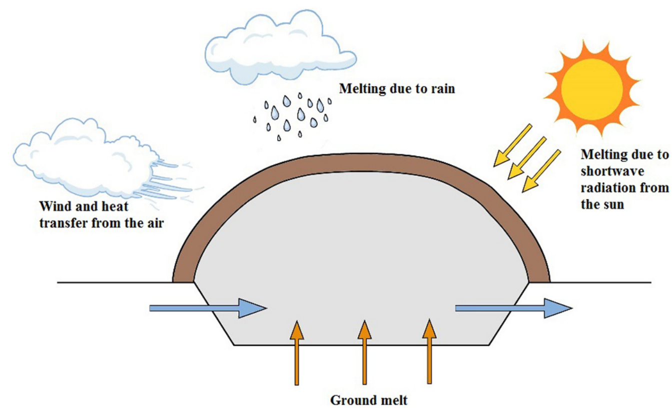

Fig. 2. Factors affecting the melting rate of an insulated pile of snow are ground melt which is due to heat transfer through the ground, surface melt which includes heat transfer from the air, sun and sky and rain melt (Modified after Skogsberg, 2005).

The optimum design for snow storage is not yet fully understood. The objective of this paper is to review and summarize current knowledge and experiences from some places where snow has been stored and to present new results from practical experiments of snow storages. Furthermore, a theoretical model is retrieved for theoretically estimating melting losses of insulated snow depots. Results from theoretical calculations are compared to the practical experiments. The calculated results of melting losses prove to agree well with measured values, showing that such a model can be useful when designing snow storages. Theoretical calculations can be used for choosing the geometry of the pile, type and amount of insulating material needed and for determining the initial amount of snow needed in order to preserve the desired amount for the upcoming winter season.

2. Knowledge regarding snow storage

2.1. Mass and heat transfer in an insulated snow depot

The mass and heat transfer through a porous material used as thermal insulation for a snow depot placed on the ground, occurs through water transport, heat conduction, heat convection and radiation (Skogsberg and Lundberg, 2005). This is illustrated in Fig. 3. The radiation exchange at the surface of the insulating layer includes both short wave radiation from the sun and long wave radiation, i.e. heat. The convective heat and mass transfer is according to Skogsberg and Lundberg (2005) influenced by the temperature, humidity, wind velocity and the properties of the insulating layer such as surface roughness of the material, water transport capacity and compaction. The thermal conductivity depends on the properties of the insulating material, such as structure, density and moisture content. The energy conduction rate