Suppression of Evaporation from Snow-Fields

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Abstract

An outline is given of the possibilities to utilize surface films for the suppression of evaporation from snow surfaces. Special measures must be taken to ensure the spreading of the films at the low temperatures in question. Preliminary laboratory and field experiments demonstrate the effect of fatty alcohol films on snow, but definite conclusions as to the ultimate possibilities of the methods and feasibility of their application on a large scale cannot yet be drawn.

The increasing use of available water resources raises the interest in artificial control of the geophysical water balance, in order to make more water available e.g. for the production of electric power and for agriculture and forestry. One way to attain a more effective water economy is to suppress the evaporation from suitable water, snow and ice surfaces. In Australia, British East Africa, and the U.S.A. intensive work is going on to investigate the control of evaporation from water reservoirs by means of monomolecular films of fatty alcohols, mainly hexadecanol.

The experimental work on snow fields has so far been limited to the reduction of the albedo by spreading of substances such as soot or gravel. This generally causes an increasing rate of melt and increasing evaporation as well.

The present work is concerned with the suppression of evaporation from snow and ice surfaces by monomolecular films of fatty alcohols in parallel with the work on water surfaces. However, controlling the evaporation from snow surfaces includes several new difficulties.

a. The snow and ice surface have a much lower temperature than the water surfaces in regions where field tests on evaporation control are being performed. This means that in the former case the rate of formation of a monomolecular film from fatty alcohols in the solid phase is likely to be much lower if not zero.

b. The effective surface of a deep snow layer is very large and the amounts of fatty alcohol necessary for formation of a monolayer around every snow particle would be impractical.

The information obtained from research work on the control of evaporation from water surfaces therefore has to be reconsidered before it can be applied to studies on evaporation from snow surfaces.

The major problem in forcing a fatty alcohol to spread on a cold surface is the provision of the energy required for the transition from the solid phase to the film. This can be accomplished by adding a pigment to the substance, thus forming an absorber for the solar radiation. During insolation the surface temperature of the pigment particles is supposed to increase sufficiently for film formation. There may be several other means to facilitate the film formation, e.g. the choice of alcohol, admixture of substances disturbing the crystal lattice, such as camphor or solvents as mentioned in the experimental part.

If it were necessary to cover the surfaces of

all snow particles in a deep snow layer, the economic possibilities of the method described would be very small. However, the evaporation takes place mostly from the snow particles at or near to the surface. Accordingly, it is only necessary to cover these particles. This might be effected by spreading a fatty alcohol mixture on the surface forming storage centra of slowly spreading material. The spreading downwards in the snow layer is supposed to be limited to the region where the insolation causes the snow particles to be covered with a water film and to have a relatively high surface temperature.

Snow falling after the spreading of the fatty alcohol mixture decreases the effect of the film until the new snow particles have been covered by a water film allowing the spreading upwards of material from the storage centra on the former snow surface.

It is obvious that the spreading of the fatty alcohol mixture ought to be made rather late during the spring to avoid new snow as far as possible.

Experimental part

The experimental work has so far included laboratory experiments and open-air experiments. In both cases the experimental difficulties are very great. In the laboratory experiments, e.g., it is hard to keep the snow surfaces free from contamination and working in the open air the meteorological conditions are mostly not ideal for the experiments. The experimental difficulties will be further discussed at the end of the paper.

Laboratory experiments

Most of the experiments were performed in northern Lapland during the spring 1955 in a small shed on the ice of Stora Lulevatten. In this case the laboratory equipment was very simple but pure, snow was easily available. Later experiments have been made during the first months of 1957 in my laboratory on the Lidingö island near Stockholm. Here the laboratory equipment was better but it was nearly impossible to find snow pure enough.

Snow was filled into cubical containers of stainless steel holding 1 litre and the surface cut plane with a clean knife. The vessels were dusted with different fatty alcohol mixtures and exposed to radiation and wind. The radiation came from two watercooled super high pressure mercury lamps, each of which consumed 500 watts, and two infrared radiators, each of which consumed 250 watts. The distance between the radiators and the snow surface was 100 cm or less. The wind came from a small fan-blower at a distance of 70 cm from the snow containers. The wind velocity was 2—3 m/sec.

In order to get exactly the same treatment of all the vessels in the same run the containers were successively permutated every half or whole minute. In each series usually 6 containers were treated and of these two were reserved for blancs. The air temperature and the relative humidity were observed during the experiments.

Among others the substances listed in Table 1 were tested.

Table 1

Substance	Composition
0	cis-9-Octadecen-1-ol, techn. grade.
1	1-Hexadecanol, techn. grade, 30 %; 1-Octadecanol, techn. grade, 70 %
2	1-Hexadecanol, techn. grade
5	Substance nr 1, 50 %; Finely powdered red iron exide, 50 %
13	Substance nr 1, 90 %; Camphor, 10 %

In the 1955 experiments the amount of test substance dusted or sprayed on the containers could not be measured exactly but was estimated to be 1—5 mg pro sq. dm. In the 1957 experiments it has been possible to determine the amount of test substance somewhat more exactly.

In most of the evaporation series the containers were dusted immediately before the start of the evaporation test. The results from some evaporation runs are found in Table 2 for the 1955 experiments and in Table 3 for the 1957 experiments. In Table 4 the maximum efficiency observed for the various substances is given.

In some experiments the containers, when filled with snow and dusted with the test substances, were allowed to stand in a cold protected place for 24 hours before the measurement of evaporation was started. The

Plate I. Spreading of substance nr 5 by an air-blower.

Plate II. Test area treated with substance nr 5, 28.3.56 and photographed 28.4.56.

Plate III. Test area treated with substance nr 5, 28.3.56 and photographed 28.4.56.

Plate IV. The same area as on plate III photographed 11.5.56 from a somewhat larger distance.

Table 2

Some results of evaporation tests 1955

Exp. no.	Date	Evaporation from Reference Surface mm/hour	Relative evaporation of sample treated with substance no.				Duration of test
			0	1	2	5	
6/55	16/3	0.03	87 %	92 %	96 %	102 %	5 hrs
10/00	19/3	0.2	80 %	92 %[1]	99 %	90 %	50 min.
11/55	4/9	0.2		88 %	—	—	4 hrs.

Table 3

Some results of evaporation tests in 1957

Exp. no.	Date	Evaporation from Reference Surface mm/hour	Samples treated with substance no.						Duration of test
			0		2		13		
			Amount mg/m²	Relative evaporation	Amount mg/m²	Relative evaporation	Amount mg/m²	Relative evaporation	
10/57	26/2	0.03	400	85 %	150	93 %	180	90 %	23 hrs
11/57	28/2	0.1	1000	87 %	100	91 %	100	91 %	24 hrs

Table 4

Highest efficiency observed for some test substances

Substance no.	Date	Relative evaporation observed	Amount of material applied (mg/m²)	Duration of test
0	28/2 1957	78 %	1000	24 hrs
1	4/4 1955	84 %		35 min.
2	16/3 1955	78 %		40 min.
5	19/2 1957	50 %	150	60 min.
13	25/2 1957	88 %	1000	7 hrs

Table 5

Film penetration through overlying snow

Exp. no.	Date	Evaporation from ref. Surface mm/hour	Relative evaporation substances				Duration of test
			0	1	2	5	
8/55	19/3	0.3	80 %	99 %	98 %	99 %	42 min.
9/55	19/3	0.3	104 %	103 %	104 %	89 %	45 min.

results obtained in this way were of the same order of magnitude as those obtained in the usual experiments.

After one series of evaporation tests the containers, now half filled with melting snow, were refilled with fresh snow, and allowed to stand in a cold protected place for 3 days. A new series of evaporation tests were then made. The results are given in Table 5, experiment 8/55. The container originally sprayed with substance 0 showed 20 % suppression of the evaporation.

In another interesting series of evaporation tests the containers were originally filled with

snow to the half of the height, then dusted and to the end completely filled with snow. (See Table 5, experiment 9/55.) In this series the container dusted with substance No. 5 showed a definite suppression of the evaporation during a 45 min. period of irradiation. It is of special interest to note that the colour of the red iron oxide showed up at the surface as soon as 20 min. after the start of the irradiation.

Both of these experiments indicate that the fatty alcohols used do possess a notable spreading power in the vertical direction. This has direct application to the penetration of newly fallen snow.

Open air experiments

The open-air experiments were started in the late spring of 1954 and were continued during the spring of 1955 and 1956. All experiments were made in the neighbourhood of Stora Lulevatten in Lapland. For the dusting of fatty alcohol mixtures various methods were tried. Among others the motor-driven air blower shown on Plate I was tried. The aim was to dust an amount of 15 mg/sq. m of fatty alcohol and correspondingly 30 mg/sq. m of mixtures containing 50 % red iron oxide. Of course rather great variations were obtained. A more uniform layer might be obtained when dusting from an aircraft.

In spite of newly fallen snow and drifting snow the rate of melt was increased so far that the treated snow surfaces were free from snow a week or a fortnight earlier than the reference areas.

On Plate II a test area is shown which was treated with substance No. 5. The photograph was taken one month after dusting. Ten days after dusting a four-day period of snowfall occurred leaving 10 cm of new snow on top of the alcohol layer. Still the colour is clearly visible 16 days later and a definite border is formed against the untreated area at the upper left of the photograph.

The test area shown on Plate III och IV was treated 28. 3. 56 and the photographs were taken 28. 4. 56 and 11. 5. 56. The snowfall mentioned above occurred 9. 4.—13. 4. The effect of varying density of the fatty alcohol layer may be observed.

Discussion of results

The results obtained in the experiments described are promising but not conclusive as to the ultimate possibilities of controlling the evaporation from snow surfaces. The experimental difficulties are great. In the laboratory experiments utmost care must be taken to avoid contamination of the snow surfaces and in the open-air experiments it is very hard to determine the effects of evaporation suppression.

The irregularities observed in the laboratory experiments might be explained by one or more of the following reasons. The original snow sample might be contaminated with the consequence that the film formation is hindered. During the experiment the snow sample might be contaminated by particles carried with the air stream from the fan blower. When filling the containers the snow packing is irregularly disturbed and accordingly the rate of sinking of the snow surfaces during the evaporation test is not the same in all the containers. At the walls of the containers the melting is faster than in the bulk of the snow. This means that new surfaces are formed at the walls which influence the evaporation.

The snow used during the 1955 experiments was found to be very pure, while the snow available in the 1957 experiments was contaminated with soot and residues of fuel oil. With the naked eye one could see that the spreading of the alcohol mixtures containing pigment was much slower on the contaminated snow than on the pure one.

An even distribution of the minute amounts necessary to cover the 100 sq. cm surface of the containers is very difficult to obtain. Therefore a considerable overdosage was necessary to secure a complete coverage of the test surface. Such an overdosage might also be motivated by the short time scales involved in the experiments, in contrast to natural conditions under which the film would have considerable time to spread.

When comparing the results obtained with the mixture of octadecanol and hexadecanol, and this mixture in combination with red iron oxide, the general experience is that the pigment positively effects the spreading power. Probably the octadecenol has a still greater spreading power.

The penetration through a snow layer in the vertical direction was demonstrated for octadecanol and the pigmented fatty alcohol mixture in experiments Nos. 8/55 and 9/55. As obvious from the varying results in Table 5 these conclusions are still uncertain. However, in this type of experiments it is more probable that accidental disturbances would inhibit the suppression of evaporation than the opposite.

To increase the spreading power of the saturated long chain alcohols camphor has been added to disturb the crystal lattice as in substance No. 13. The results so far obtained are inconclusive.

Spreading from 5—30 % solutions in a mixture of benzene, methanol and light petrol in the proportions 10—10—80 has shown no essential improvements in the results.

The ideal substance ought to have a certain spreading power but it is obvious that a substance too easily spread might expand downwards over the enormous effective surface of a thick snow layer and in this way lose its effectiveness.

In northern Sweden the spring melt off lasts at least 2 months. During this time there is usually a long period with thawing during clear days and freezing at night. This process results in very coarse snow crystals and an effective surface diminishing for every recrystallization. Accordingly an amount of fatty alcohol, which from the beginning is quite unsatisfying might at the end be able to cover the whole effective surface of the top layer.

Studying the heat balance provides a possibility so judge the effect of the surface films. A suppression of the evaporation from the snow surface makes more heat available for melting. The melt off as compared with untreated surfaces is thus an indication of the effect of the surface treatment. However, if a pigment containing mixture is used, as was generally the case in the open-air experiments, the heat balance of the snow is also affected by the change in albedo, which makes such a direct comparison impossible. Other methods to make a direct determination of the evaporation suppression have been tried but so far no conclusive results have been gained. It is obvious from the laboratory experiments that the pigment-alcohol mixtures produce a suppression of the evaporation in spite of the fact that the energy absorption is increased, which normally ought to cause increased evaporation losses. It may thus be inferred that this is also the case in the open-air experiments.

The evaporation losses in northern Sweden during the melt off season are 30—60 mm water. If the treatment with 30 kg/sq. km of pigmented fatty alcohols could reduce the evaporation by approximately one third, the enterprise would be economically well worth while in certain areas. In regions where the normal evaporation losses are much greater, e.g. the Rocky Mountains or the Alps, the treatment would be economical with considerably lower relative gains.

The investigations will be continued with more refined laboratory and open-air experiments.

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