City snow’s physicochemical property affects snow disposal

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Abstract
At the present day the industrial cities run into severe problem: fallen snow in a city it’s a concentrator of pollutants and their quantity is constantly increasing by technology development. Pollution of snow increases because of emission of gases to the atmosphere by cars and factories. Large accumulation of polluted snow engenders many vexed ecological problems. That’s why we need a new, non-polluting, scientifically based method of snow disposal. This paper investigates polluted snow’s physicochemical property effects on snow melting. A distinctive feature of the ion accelerators with self-magnetically insulated diode is that there.

1. Introduction
As is well-known snow it’s a type of atmospheric widespread precipitation consisting of small ice crystals and falling out in certain meteorological conditions. Singularity of snow cover it’s ice layers which effects on snow characteristics [1].

Snow cover has a clearly defined layering because of different meteorological conditions during the deposition of snow. These characteristics are the main reason of snow inhomogeneity, but snow is generally thought to be homogeneous if we want to find out basic characteristics.

Table 1. A number of key parameters represented

| Characteristic   | Unit          | Notation |
|------------------|---------------|----------|
| humidity         | % (by weight) | W        |
| density          | kg/m³         | ρ        |
| temperature      | °C            | T        |
| heatcapacity     | J/K           | C        |
| blend composition|               |          |
| - salt content   | % (by weight) | S        |
| - solids content | % (by weight) | G        |

Snow pack humidity is an indicator of liquid phase volume, and has an importance at determining the disposal optimum. Humidity generally depend on snow temperature, therefore also depend on atmospheric temperature; and for new-fallen snow humidity can vary between 1% and 25%. The calculating humidity, depending on temperature, formula: \( W = (k_1 - k_2) \cdot T \).
Snow humidity; T-snow temperature (in modulus); $k_1$ - coefficient, depending on basic snow characteristics, $1/{^\circ}C$, $k_1 = (12; 15)$; $k_2$ - coefficient, depending on external factors, $k_2 = (1.5; 2)$.

This formula is correct for temperatures vary between the 0 deg. C and the 8 deg. C. Ground snowpack falls and is shoveled away at this temperature. So we will use this form to calculate snowpack humidity. Humidity can be finding by centrifugal process with a calorimetric method or by the measurement of different chemicals dissolution rate. But all of these measurements are time-sapping or difficult to unity [2].

Because of these reasons the international snow classification divides snow into dry, damp, wet, soggy, and slush.

The calculating density formula: $p = \frac{m_c}{V_w}$

$m_c$ – mass of snow; $V_w$ – water volume after thawing.

Density largely affects the disposal process, for this reason this parameter value must be true. Snow density be depending on different conditions can vary between 1 t/m$^3$ end 0, 9 t/m$^3$. Naturally snow density is about 0,2t/m$^3$, new-fallen snow density - 0,1 t/m$^3$, snow slush at a snow dump is about 0,6 – 0,8t/m$^3$. Statistics about snow density, which take away from Tyumen streets, mean density is 0,3 t/m$^3$. Snowpack temperature is a base parameter to determinate how snowpack characteristics vary with its parameters. Usual the snow temperature is about the atmospheric temperature.

### 2. Another section of your paper

Snow component composition greatly varies with heat required to thawing. There are a lot of glaciological and petro physical studies about snowpack depending on pollution. But these studies don’t carry inference about salts and mud depending on the snow disposal.

Researches show a high level of city snow pollution. A mean of common pollution agents are greatly changed for different city sectors (Table 2).

Snow samples include a lot of suspended solids, slow bio oxidizable organic compounds and hardness salts. Chlorides content exceed MPC 7 - 15-fold; sulphates content – 5-fold. Toxic metal ion concentration (ferrum, manganese, lithium, zinc, cuprum, molybdenum, cobalt, cadmium) exceed MPC from 1 to 46 times. Oil-products and phenols content exceed MPC from 25 to 150 times and from 1 to 4 times respectively [3,4].

| Agents            | Dimension | Rate    |
|-------------------|-----------|---------|
| Suspended solids  | mg/l      | 121 – 732 |
| Ammonium          | mg/l      | 0,33-9,6  |
| Chlorides         | mg/l      | 16,11-338,2 |
| Sodium            | mg/l      | 13,76-442,4 |
| Potassium         | mg/l      | 22,3-110,9 |
| Ferrum            | mg/l      | 0,68-1,45  |
| Manganese         | mg/l      | 0,11-0,67  |
| Zink              | mg/l      | 0,013-0,09  |
| Plumb             | mg/l      | 15,23-37,23 |
| Oil-products      | mg/l      | 1,4-50,2   |
| Detergent         | mg/l      | 0,23-1,012  |

A data analysis has shown that main volume of pollution agents consist of suspended solids; oil-products and chlorides: the mean suspended solids concentration equal to 426,5 mg/l occurs with 27%
probability; the mean oil-products concentration equal to 25.6 mg/l occurs with 33% probability; the
mean chlorides concentration equal to 177.2 mg/l occurs with 28% probability.

For a theoretical estimate of interphasic heat exchange processes going in the snow melting
chamber, a mathematical model basic on actual heat exchange conditions was created. In this model
we deal with a problem of heat exchange between liquid and a separate fragment of solid body in the
form of a cube for clarity. Also we evaluate the effect of local heat exchange processes sum on
interfusion heat exchange integral characteristic [5,6].

We shall deal with the problem of heat exchange between liquid and a separate fragment of solid
body. Suppose the solid cube with side $V = v^3\left(v - \text{volume of solid}\right)$ is immersed in liquid. The liquid
temperature ($T_f$) is higher than solid fusion temperature, and melting taking place at temperatures
between $T_{1s}$ and $T_{2s}$, $T_{2s} > T_{1s}$. In this case molten zone, closed by surfaces which shift deep into the
solid body during the time, is arisen. In the molten zone fusion heat release; and location of molten
borders depends on balance between the heat for fluxes on borders and the heat essential to melting.

In the snow melting chamber, containing mix of heated liquid and ice fragments, a low permanent
current is maintained. Therefore a rate of heat exchange processes in the perpendicular direction of
flux is stronger than in right direction of flux. So, for the system: liquid - solid body, we can suppose
that temperature ($T$) function of time ($t$) and one space coordinate -- $x$, in the perpendicular direction of
flux $T = T(x,t)$. Consequently our problem of heat exchange between liquid and a separate fragment of solid
body in the form of a cube changes to a problem of monadic heat exchange between liquid and an unlimited
ice plate, and the melting process is going symmetric by two opposite faces of ice plate. Let’s line $x = 0$ - is a location of one plate face at the time point $t=0; X_1(t), X_2(t) - a molten borders formula at the time point $t$, at melting temperatures $T_{1s}$ and $T_{2s}$ [7].

If we use indexes 1, 2 and 3 for three molten zones we’ll get a set of equations for required functions.

\[
\frac{\partial T_1}{\partial t} = a_1^2 \frac{\partial^2 T_1}{\partial x^2} \quad ((t \geq 0, 0 \leq x \leq X_1(t)) \quad (3)
\]
\[
\frac{\partial T_2}{\partial t} = a_2^2 \frac{\partial^2 T_2}{\partial x^2} \quad ((t \geq 0, X_1(t) \leq x \leq X_2(t)) \quad (4)
\]
\[
\frac{\partial T_3}{\partial t} = a_3^2 \frac{\partial^2 T_3}{\partial x^2} \quad ((t \geq 0, X_2(t) \leq x)) \quad (5)
\]

$a_j = \frac{K_j}{C_j \rho_j}$ - a temperature conductivity coefficient for city snow component (j),

$K_j$ - a thermal conduction coefficient for city snow component (j),

$C_j$ - a specific heat for city snow component (j),

$\rho_j$ - density for city snow component.

Formula (6) was written subject to the following restrictions.

Suppose that heat input, depending on the second zone temperature, at a steady pace, than heat
input by melting will be calculated approximately, using following meaning of specific heat:

\[
C_2 = C_1 + \frac{1}{T_{2s} - T_{1s}}
\]

$C_1$ - liquid specific heat, $\lambda$ -- specific heat of melting.

As follows from experiment results, city snow in the snow melting chamber amount to snow-iced
pack with so huge quantity of multicomponent mixture, that we can’t neglect their effect on the
melting process. In the first case, neglecting an interaction heat effect, we will suppose additive and
admission of mix thermo physical properties:

\[
K_j = \sum_i K_j l_i, C_j = \sum_i K_j l_i, \rho_j = \sum_i K_j l_i
\]

$l_i$ -- mass concentration of i- pollution ($i = 1, \ldots, n$) in city snow.

Solution of thermal conduction (8)-(10):

\[
T_1 = A_1 + B_1 \Phi\left(\frac{x}{2a_1 \sqrt{t}}\right)
\]
\[
T_2 = A_2 + B_2 \Phi\left(\frac{x}{2a\sqrt{t}}\right) \quad (9)
\]
\[
T_3 = A_3 + B_{31} \Phi\left(\frac{x}{2a\sqrt{t}}\right) \quad (10)
\]

\[A_j, B_j, j = (1, 3)\]-constants, \(\Phi(Z) = \frac{2}{\sqrt{\pi}} \int_0^Z e^{-\xi^2} d\xi\) - error function. Constant sat equations (8)-(10) deduce from first and boundary conditions. Let's measure outcomes of ice melting in the snow melting chamber. If ice fragments cube with volume and side, than a border square, and mass of melted ice per second will be: \(\Delta m_i = 2\frac{\alpha x_i}{at}(v_i) \cdot \rho\). Let us denote number of ice fragment by \(n_i\), size between \((v_i)\) and \((v_i + \Delta v)\). If we suppose that volume of ice fragments in mix follow the normal distribution law with characteristics \(\mu(v) = v_i, S(v) = \sigma\), than the random variate density will be:

\[
f(v) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\left(\frac{(v-v_i)^2}{2\sigma^2}\right)} \quad (11)
\]

Number of ice fragments with size between \((v_i)\) and \((v_i + \Delta v)\) will be:

\[
n_i \approx f(v_i)\Delta v_i = \frac{1}{\sigma \sqrt{2\pi}} e^{-\left(\frac{(v-v_i)^2}{2\sigma^2}\right)} \quad (12)
\]

Than mass of melted snow per second will be:

\[
M \approx \sum_i^N \Delta m_i = 2\frac{\alpha x_i}{at}\rho \sum_i^N n_i v_i^2 = 2\rho \frac{\alpha x_i}{at} f(v_i)v_i^2 \Delta v
\]

Sum in the left-hand member of an equation (13) is integral sum for continuous function \(f(v_i)v_i^2\).

So, for a snow mass estimation melting per second, taking into account the three sigma rule, we use next equation:

\[
M \approx 2\rho \frac{\alpha x_i}{at}\frac{1}{\sigma \sqrt{2\pi}} \int_{v_i-3\sigma}^{v_i+3\sigma} e^{-\left(\frac{(v-v_i)^2}{2\sigma^2}\right)} dv
\]

(14)

For analysis we use the program «Maple-7», realizing a chord method for system of nonlinear transcendental equations. The following are results for every phase of program scheme. System of equations was changed to dimensionless form by using typical test value at a temperature of 0 degrees for all dimensional quantities.

Graph 1 displays trend of the thermal conductivity coefficient loading \((a)\) of snow-iced pack, taking from city area, in model cube volume, using test data of winter 2013/2014 at Tyumen, depending on total density \((\rho)\) and total thermal conduction coefficient \((K)\) at a constant heat capacity.

**Figure 1.** The thermal conductivity coefficient loading \((a)\) of snow-iced pack depending on total density \((\rho)\) and total thermal conduction coefficient of pollute snow \((K)\).

As far as density is valuation of pollution, at graph №1 we can see that exists a critical pollution level changing snow thermo physical properties. From now on it should be figure on any snow melting
chambers. Test data show total snow-iced pack pollution, taking from city area, exceeds critical level – 2-fold. But fast growth of thermal conductivity; mean proportional decreasing of thermal capacity. And, as we can see at the graph, snow pack density have a little effect on the growth of thermal conductivity. So, for melting same volume of snow we can reduce sewage drain flow or use lower temperature drain. As follows from analytical results at graph №2, melting temperature - density relationship with pollution rising is a non-monotonic function with max, which is evidence of even one liquidus line at phasing diagram of multiphase system – city snow, telling about a new phase origin - chemical mixture, with melting temperature beyond the natural snow melting temperature.

**Figure 2.** Dependency graph $T_m(L)$, phase 3-solid body

It’s important that increase of melting temperature requires increase of sewage drain flow, as follows from analytical results at graph №2. Turn attention to analysis results at graph №3. As we can see, relationship between solid body melting temperature and thermal capacity with total pollution, (uniform dependence for natural snow), in this case have two local maximums and one local minimum. It shows two facts. First, if city snow has pollutants, applying deicing agent, a layer structure with two non-overlapping range of melting will come up.

**Figure 3.** Dependency graph $T_m(C)$, phase 3-solid body

Second, if such structure comes up in snow melting chamber, one part of snow-iced pack will melt completely at set temperature point of sewage drain, but another more heatproof part can create a cork in interceptor. In that case if sewage drain, like coolant, has characteristics designed for more heatproof part, we have to control flow in real time.

3. Conclusion
As follows from analytical results at graph №1-3, snow pollution leads to nonlinear and non-monotonic changing of the melting temperature by density, and density is an additive function of pollution. In certain pollution value clear-cut zones of peak snow-iced melting temperature are seen at all graphs. Obviously, for so pollute snowpack melting need greater heat flow than for natural snow. Let’s view a snow disposal. Basic method of snow disposal is removal by special automotive
equipment. This method is very expensive (several billions rubles for one wintertime), and pollutes urban ecosystem.

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