Impact of Physical and Mechanical Characteristics of Snow on the Melting Process Intensity

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Abstract. The most economical decision to remove snow in big cities is using thermal snow melting facilities. Snow mass removal, taking place within them, is a complex stochastic process. Nevertheless, it’s necessary to have detailed description of melting metamorphism, allowing to get certain regularities, which could be basis of engineering calculations of geometrical and kinematic parameters of the facilities.

Methods and results of experimental studies, conducted with the purpose to find out dynamics of melting process depending on basic factors, effecting operational process: density of snow mass, grades of its pollution, temperature of heat carrier and character of its interaction with processed environment, have been narrated in the article. The received experiment results are foundation for physical modelling of operational process and getting criterion equations as dimensionless quantities for distribution of found relations for all the similar systems.

1. Introduction

After making calculation of expenses connected with export of snow mass behind city limits and also with necessary ecological actions pertaining to protection and restoration of environmental management objects many city administrations conclude that it will be expediently to remove snow mass. With that purpose snow melting facilities are in high demand, exploited in winter. Despite of the type of the facilities, snow, melted in them, after transition into liquid phase, gets into central sewerage system and then – to sewerage disposal plant. Thus, problem of melt water refining from harmful impurities is solved [1,2]. Using of snow melting facilities (especially mobile ones) allows to cut down expenses of city’s municipal services to exploit transport [3,4].

2. Condition of the issue and setting the research tasks

There are a lot of probable constructive variants of snow melting facilities by world-wide known manufacturers as well as by Russian ones for purchasing and usage: transportable, mobile, roofing (assembled on roofs of objects), stationary. As a source of heat waste waters, water supply system, vapour, water-heating boilers operating due to any type of fuel (gaseous, liquid, solid), electric heating elements can be used [5,6].

Depending on constructive and technological decision snow melting facilities have certain specifics of conducting operational processes. This specifics must be considered in the process of theoretical description of summary impact of local heat exchange processes and, as a result, selection of
kinematic and geometrical parameters of the facilities for engineering calculations with supplying with high intensity of phase transition and, therefore, high efficiency of exploitation has been proved [7,8].

There are the results of theoretical estimation of interphase heat exchange processes and stationary snow melting facilities, operating due to usage of heat of sewage runoff [9]. In particular, task about heat exchange between liquid and isolated fragment of a solid body having the cubic shape, has been considered. Total impacts of local heat exchange processes on integral heat-exchanging characteristics of a mix have been assessed. Such an approach is adequate for the considered type of the facilities only. Within them intensity of heat-exchanging processes between heated liquid and snow mass happens in the direction perpendicular to the direction of the heat carrier’s stream having weak flow.

On the basis of some experimental studies [10] recommendations for improvement of the design of snow melting facilities have been worked out by authors [11]. Operational process goes on in a more intensive way due to using active operating mechanisms and circulation loop of heat carrier (hot water), supplied under pressure within them.

Removal of snow mass, conducted within such snow melting facilities, is a stochastic process. Pattern of the movement of heterogenic environment is really complex, because rates of streams movement of a heat carrier are not similar, and particles of melted mass move in a chaotic torrent on an accidental trajectory. Dynamics of heterogenic structures as well as a row of other theories (viscoelasticity, plasticity, and others) is more often based on continuum mechanics in literary sources [12,13,14]. However, it’s necessary to consider that structure of snow melting facilities is based on change of aggregate state of water (phase transition from solid state into liquid one). It’s known that these processes are studied within the theory of heat mass exchange where statistical or phenomenological methods are widely used [15,16].

After multifold analysis of possible theoretical approaches, assessments of got resources and knowledge collected by the authors [17,18], for description of operational process of a snow melting facility, usage of similarity theory and physical modelling is offered. A priory it was clear, that similarity criterion equation, describing operational process, besides geometrical and kinematical parameters of physical model must be among physical and mechanical properties – density of snow mass, grade of its pollution, temperature of heat carrier. There was preliminary assessment of impact of these parameters on melting process intensity at this very level among research tasks.

3. Methods and results of researches

Complex of experimental studies was conducted in March. Choice of the season is explained with the fact that difference of daily temperatures during this very season lead to active natural spontaneous snow mass compacting. Moreover, to this very season maximal influence of technogenic impacts, expressing at the areas where snow hasn’t been removed during winter, collect.

At the first stage interval of possible changes of snow density have been determined till the moment of its download into snow melting bunker (after removal, transporting and warehousing). Measurements have been conducted in “Tyumen motor-road transport department of the direction of technological transport and special equipment of the “Gazprom transgas Surgut” LLC”. The enterprise exploits snow melting facility, made with the purpose of decrease of expenses to support its own areas. Operation of the facility is based on the principal of forced circulation of heat carrier (Figure 1). As snow was collecting just after its fall and just from enterprise’s own area, where none of deicing actions take place, it didn’t contain suspended impurities, influencing density change. The climate monitor has fixed that March of the current year in the Tyumen city was abnormal, and level of snowfalls was 43 mm (253 % of norm). During all the month the snow melting facility was exploited in an enough active way, that facilitated preparation and access to research. The experiments were conducted in more snowy days and allowed to determine total range of changes of snow density before loading it and its average values (Figure 2). The manufactured device for density measurement was used similar to snow gauge BC-43 (State Register of gages No. 22529-02). In addition to it a mould which’s dimensions were 10*10*10 centimetres was used. Within this mould due to layer-by-layer compaction models were formed and the maximum achievable (reference) density of snow for every
different day of experiments conducting. The expediency of results comparison for every day was proved with various air temperature and, therefore, with various snow humidity.

Every charging into snow melting bunker was expedited with direct vision and photofixation with the purpose to evaluate quantity of body to melt not in the form of condensed balls, but in a messy state. Density of such a body according the procedure of measurements was from 110 till 150 kg/m³, and quantity was – 15-20 % of charging scope. In the process of experiments temperature of surrounding air and snow was measured (in the depth of the body).

![Figure 1. Working process of a snow melter.](image1)

![Figure 2. The overall range of snow density changes.](image2)

At the next stage it was necessary to determine the range of possible changes of snow density depending on presence of suspended contaminations and their influence on intensity of melting process.

Sampling was implemented in the Dambovskaya street in the Tyumen city in the area of bridge constructing over the Tura River and constructing of traffic intersection in the same area. In the appointed area in winter just shift of snow from carriageway to roadside was implemented without removal and exporting. Thus, snow mass with concentrated contents of suspended particles that got into it as a result of soil and sand transportation with dump trucks, formed. This concentration exceeded possible quantity of suspended particles getting onto traffic-bearing surface in the course of scheduled deicing actions (distribution of sand and gravel mix with chemical reagents).

Samples were cut down of snow mass having heterogeneous structure, that’s why they were of different volume and shape (Figure 3).

![Figure 3. General view of samples of the snow mass.](image3)

Termination of samples scope was performed with water displacement method (Archimedes' principle). The method had been tested with reference sample of correct shape before the start of the experiments. The sample was plunged into a container of water. The forced out water drained into a
tray under the container, and then the water’s scope was measured in a volumetric flask. The result was compared to the known scope of the reference sample. Relative error, connected with losses of water on the walls of the container and the tray, didn’t exceed 3%.

The sequence of experiments and measurements was following: after weighing every sample (Figure 4) it was forcibly plunged with thongs into the container with heat carrier (water, heated to a certain basic temperature), installed on the tray (Figure 5).

The water, forced out with the sample drained into the tray, and after that the forced plunge was stopped, and the sample held on floating. Time since the moment of sample’s plunge into the heat carrier to the termination of melting was fixed. Heat carrier’s temperature was taken at the moment of phase transition termination. Then the container was removed from the tray and brought to the place of filtering. After measuring water quantity, collected from the tray, actual density was calculated. The heat carrier from the container was filtered, and collected suspended particles were directed to an oven (LF-60/350-GG1). The next weighing of solid particles allowed to calculate their actual quantity relating the sample’s scope as weight and percentage ratio. For assessment of weight of solid particles as solid composition sifting through a bolter was implemented (GOST 8735-88).

For every following sample the heat carrier’s temperature was increased to the necessary initial condition, and the whole procedure was repeated. The results of the measurement are contained in the table № 1.

| №  | Volume (cm³) | Weight (gm) | Melting time (s) | Temperature change (°C) | Density (kg / m³) | Suspended substances (gm) | % |
|----|--------------|-------------|-----------------|------------------------|------------------|---------------------------|---|
| 1  | 687          | 526         | 179             | 2                      | 699              | 34                        | 6.46 |
| 2  | 923          | 643         | 190             | 3                      | 697              | 47                        | 7.31 |
| 3  | 1271         | 877         | 285             | 4                      | 690              | 83                        | 9.46 |
| 4  | 1038         | 713         | 250             | 3                      | 687              | 71                        | 9.96 |
| 5  | 743          | 513         | 175             | 2                      | 690              | 31                        | 6.04 |
| 6  | 723          | 493         | 154             | 2                      | 682              | 32                        | 6.49 |

The important factor, influencing the melting rate, is the heat carrier’s temperature. For assessment of influence of this factor a number of experiments with measurement of initial temperature from 30 to 80 degrees Celsius has been conducted. The reference samples with dimensions 10*10*10 centimetres were undergoing melting, formed due to layer-by-layer compaction of snow without suspended contaminations.
4. Discussion, conclusion, recommendations

The results of the experiments, represented above, are initial data for proof of choice of values or ranges of parameters variation in the course of the following studies of the operational process with the physical model of the snow melting facility.

As it has been determined, in the removal process, transporting and warehousing of snow, its basic body gets preliminary compaction in the interval from 370 till 530 kg/m³. Temperature increase of the surrounding air and the temperature of the snow itself leads to increase of humidity, and, as a result, to the increase of density caused by snow removal machines. It was determined with direct control and photofixation, that quantity of messy snow (density is 130 +/- 20 kg/m³) in the course of charging in the snow melting bunker doesn’t exceed 15-20% of total scope of charging. Density of maximal compacted (reference) samples, formed of snow mass (temperature interval from 3 till 15 degrees below zero Celsius), didn’t exceed 790 +/- 20 kg/m³, that’s approximately 10% less, than ice density. Presence of suspended contaminations, even in maximal possible quantity 6-10% of the mass, increases snow mass density just till 690 +/- 10 kg/m³.

Comparison and analysis of the received results allow to recommend to use snow mass which’s density is 600 +/- 50 kg/m³ in the course of physical model research. It’s not expedient to determine the density, similar to reference one, because it can lead to significant overexpenditure of required energy consumption for melting. The recommended value of density exceeds actually received values in the course of the studies. The offered reserve (till 20%) will allow to compensate the error of modelling of operational process of melting. This error can actually appear, because certain masses, having density, close to maximal one, can get into operating facility.

The known results of the previous investigations show that total quantity of contaminations in the content of snow don’t exceed 2% of the mass [19,20]. The list of ingredients, contained in the structure of contaminates, is extensive and demands control in the course of solving of ecological issues. However, the presence of such quantity of contaminations doesn’t actually influence the intensity of melting process.

The authors had to be sure, that this statement was typical also for cases, when presence of suspended substances would be multiply higher relating average information. With that purpose, rarely met in real practice field of snow pollution was examined, when quantity of suspension was 6-10% of mass.

It was proved, that presence of suspended particles, frozen into snow mass, accelerates the process of melting. This fact is explained in such a way that heat conductivity of solid particles (sand, for instance) is higher than heat conductivity of ice and snow. For this reason on contact with heat carrier they pass heat to melted body. In the course of the next winterizing and settling-out in the place where they had been before, vacuums form, increasing square of contact with heat carrier, that also contributes to increase of melting intensity. Thus, we can state, that in the course of further investigations of the operational process of snow melting facilities the factor of presence of contaminates can be eliminated from the research as insignificant one.

It was proved, that more significant factor effecting intensity of snow mass melting is heat carrier’s temperature. Increase of heat carrier’s temperature, contacting with melted mass, decreases time of the process, however, energy consumption and unproductive losses increase (effectiveness factor decreases). It’s more clear due to dynamics of heat carrier’s temperature disparity in the beginning and in the end of the melting process. Comparison of these changes with time, spent for phase transition, allow to recommend not a certain value, but interval of temperatures. The lower class boundary of the interval corresponds to 30 degrees Celsius. The decrease of this value calls into question operability of snow facility, especially in the cases, when temperature of surrounding air is lower than 15 degrees below zero Celsius, and snow facility is exploited. The upper boundary of the interval is offered to determine no more than 60 degrees Celsius. Energy, required for heating, higher than this value, won’t be wasted, as the authors suppose. The criterion of the criterion equation, in which factor of temperature in the course of physical modelling will be included, is one of defining ones, because it characterizes heat exchange process.
5. References
[1] Shamsutdinov R G and Trotsenko I A 2016 Necessity of using snow melting stations to improve the ecological situation in Omsk Ecological problems of the region and ways to solve them pp 384-9
[2] Khaidarshina E T, Kuantaeva A A and Biktimirova C V 2017 Urban snow dumps in Ufa as a source of pollution of surface waters Ural Ecological Herald vol 1 pp 10 - 22
[3] Ketov K D and Ruchkina OI I 2016 Justification of the use of snow melting units in the city of Perm Herald of the PNIPU. Construction and architecture vol 3 pp 54 - 65
[4] Maksud N G, Bakatin Yu P and Fedyukina T V 2015 Substantiation of the choice of the energy carrier of a mobile snow melting machine for servicing adjacent areas Vestnik MADI vol 2 pp 33 - 39
[5] Sharukha A V, Madjarov T M, Kostyrenko V A and Yashnikov S P 2013 The review of machines for the melting of snow mass Transport and transport-technological systems pp 205 - 208
[6] Polyakov D V Working processes and justification of the parameters of electric snegotayalok. Cand, Diss. tech. Sciences. Tyumen 182 p
[7] Falkovich G 2011 Fluid Mechanics, a short course for physicists Cambridge University Press pp. 140 – 145
[8] Koretsky V E 2008 Modeling the process of snow melting in a snow melting chamber Vestnik MGSU vol 2 pp 173 - 179
[9] Koretsky V E 2007 Geocological foundations of the theory and practice of engineering protection of the water system of the northern megapolis during the winter. Doct, Diss tech. Sciences Moscow 293 p
[10] Serebrennikov A A, Plokhov A A and Panov V I 2017 Increase in the intensity of the working process of snow melting plants Ground transport-technological complexes and means pp 283 - 288
[11] Serebrennikov A A, Plokhov A A and Panov V I 2017 Recommendations for a stationary installation creation of snow melt New technologies for the oil and gas region pp 364 - 367
[12] Nigmatulin R I 1987 Dinamika mnogofaznykh sred [Dynamic of multiphase mediums]. Moscow: Nauka vol 1 464 p vol 2 360 p
[13] Arfken G B and Weber H J 2005 Mathematical Methods for Physicists. Sixth Edition Elsiver Academic Press 1182 p
[14] Truesdell C and Noll W 2004 The Non-Linear Field Theories of Mechanics 3rd ed Springer 602 p
[15] Kutateladze S S 1979 The fundamentals of the theory of heat transfer. Ed. 5th revision. and additional. - Moscow: Atomizdat 416 p
[16] Nakoryakov V Ye and Gorin A V 1994 Heat and mass transfer in two-phase systems. Novosibirsk
[17] Serebrennikov A A 2012 Working processes and methods for designing mixing machines with eccentric balanced vibro-exciters Doct. tech. Sciences. St. Petersburg, 2001. 353 p.
[18] Serebrennikov A F, Kuzmichyov V A Basic Principles of Vibration Mixers Design. Tyumen 174 p
[19] Sister V G and Koretsky V E 2004 Engineering and environmental protection of the northern metropolitan water system in winter Moscow 190 p
[20] Deryusheva N L 2017 Perfection of the technology of utilization of snow masses from road surfaces at stationary snow melting points of water disposal systems Cand, Diss. Sciences Moscow 128 p