

## Review

“Modelling Heat and Mass Transfer in Freezing Porous Media”

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The analysis of scientific and engineering literature in the area of heat and moisture transfer in porous media (in particular in soils) with phase changes reveals that, although relatively wide series of the periodical papers exist, considering different aspects of phase transitions in freezing soils, the number of books involving these directions of study is very restricted and were published in 1980's to 1990's. Moreover, these books consider either modeling of the heat and mass transfer on the basis of classical statement (two-zone models) without taking into account a zone of intensive phase transitions and moisture migration – kinetic zone or the geocryological investigations on the basis of the general principles of heat and moisture transfer with using the experimental research. The modeling of the processes at the level of the solutions for appropriate system of equations and calculations of the distributions for characteristic values – temperature, moisture and ice in freezing soils were not considered. Apart from new approaches to the modeling and new results obtained and presented in this book (I describe these aspects later), the book involves both the combination of modeling the heat and moisture transfer processes in porous media under phase transition conditions and applications to the practical problems concerning freezing and frozen soils. In addition on the basis of “Likeness and Dimensionalities Theory,” the principles of the treatment for experimental data, leading to generalization of the experimental results and obtaining the functional relations of the main regularities are considered (for example, subsection 1.5.2; sections 2.1 and 6.1).

The main goal of the book (as the author defines it) is sequential and systematical consideration from a unified view-point and the heat and mass transfer processes occurring in heterogeneous porous media (soil-water-ice) under phase transition conditions. New solutions and also analytical and numerical models are provided for the analysis of the freezing (thawing) processes in the soils, which have arisen in various practical problems in regions such as Canada, the United States and North-East Asia.

In my opinion the main task of the book is accomplished. The book is a generalization of the theoretical and experimental author's research. The character of the problems, new approaches to the solution and results expounded make this a useful book for theoretical scientific research and also can be used for applied engineering in the field of design and construction in cold regions under conditions of freezing and frozen soils. The numbers of chapters and book as a whole can be also useful for the students and PhD students specializing in thermal physics of phase transitions, geocryology and appropriate applied scientific fields.

It is also necessary to note that the author has considerable expertise in scientific directions presented in book that is confirmed by significant number of papers in a series of scientific Journals and citations in literature on the author's studies.

The book is well-structured: the theory is clear and well-described. As a rule, the content of the subsequent sections follows from results obtained in previous sections. This gives the book a logical structure, and thereby makes it comfortable for reading and using for practical work.

Although the apparent sometimes complexity of transformations, the results have an extremely simple form and clear physical interpretation.

In particular, as a new result, the analytical criterion for kinetic zone formation (formula 2.59) is derived as a function of soil properties and freezing conditions. This criterion plays a significant role. In theoretical directions (modeling) it facilitates, a priori, the correct choice of the solution to the problem: whether to consider the phase-transition front as including a freezing zone – a three-zone model or to consider it as a mathematical surface that divides the soil region into frozen and unfrozen zones – a two-zone model. In practical applications, this criterion allows the prediction of the kinetic zone formation in which intensive moisture migration and crystallization processes take place and thereby to analyze and chose the principle of utilization of soil as the basis for constructions.

Another example is the analytical criteria of the phase front stability (formulae 5.30 and 8.48) which are derived for the first time. These criteria are obtained for the freezing process, in which the frost heave is not observed and also in cases of its occurrence. The model assumes that the non-instantaneous crystallization process takes place in the kinetic zone, and the rate of crystallization is a function of supercooling. According to the "Likeness and Dimensionalities Theory," the stability criteria depend upon the Stefan, Lewis and Peclet numbers, on the parameter, describing the non-instantaneous kinetics of phase transitions, and also on the dimensionless parameters characterizing the frost heave process. Employing Fourier synthesis, actual front shape evolution is calculated. A new physical result is obtained, according to which the front displays a periodic morphology whose scale is essentially unrelated to that of the initial (starting) perturbation. The effect of the non-instantaneous kinetics on the front shape evolution is described. It should be also noted that stability/instability state of the phase front has a significant effect on the cryogenic structure of soil. In this book, this engineering aspect is also considered in detail (sections 5.3; 8.4).

On the basis of the general solution and correlation analysis, the simple dependence of the fluid temperature versus time in the refreezing process was derived for the pipeline, buried in the frozen soil (formula 6.59). Also obtained is one of the very important characteristics for the design and laying of the pipelines in cold regions – the time required for oil or other fluid to cool to a specified temperature during refreezing of soil, when the transport of fluid has stopped (formula 6.61).

It is necessary to note that the simplification of the general solution in order to employ it in engineering practices is a characteristic feature of the book presented.

The author gives particular attention to experimental characteristics of soil as well as to the adequacy mathematical model to the physical process. Therefore, the author takes into consideration the freezing (kinetic) zone, which is characterized by an intensive moisture migration process and phase transitions as well as by relatively great gradients of the temperature.

The equations of heat and mass transfer in the soil under phase transitions conditions, obtained by the author for heterogeneous porous media (section 1.2) involves the relaxation terms, which characterize the rate of phase transitions in non-instantaneous kinetics. Therefore, the statement of the problems includes the kinetic model. In this respect, the new experimental express-method and results relating to determination of the important characteristic for the kinetic model – time of the water crystallization in freezing porous media is proposed (section 1.5). In addition to modeling, the author applies the experimental distribution of the equilibrium unfrozen water content. The analytical approximation of this dependence on the temperature (dependence 2.15, Fig.2.9) is obtained on the basis of treatment experimental data (including experimental data of the author) according to the “Likeness and Dimensionality Theory” with utilization of the linear regression method.

The original approach is proposed for the modeling of secondary frost heave. The generalized model of this phenomenon for the freezing fine-grained soils is presented in this book (Chapter 7). In contrast to other authors who assumed that the distribution of temperature in the frozen fringe (kinetic zone) is given by a generalization of the Clapeyron relation, the author of this book recognizes the need to determine the distribution of the moisture within the frozen fringe by approximation of the experimental data for the equilibrium unfrozen water content. This distribution is the result of the complicated interaction between water, ice and the mineral skeleton during the freezing process, controlled by the external (given) temperature gradient. The generalization of the Clapeyron relation, which is used in the works, estimates only the drop of the initial freezing temperature in porous medium and does not define the connection with the external temperature gradient, which is responsible for the frost heave process. This very important physical aspect is discussed in detail in the book (section 7.1). In this way, the new results, concerned with frost heave distribution and its rate, are presented. A singularity of the problem and asymptotic solutions are derived and discussed (section7.4).

Also obtained and discussed in detail are a number of new results, concerned with Miller’s and Gilpin’s models for “thermo regulation” process. The comparison between calculations results which is carried out according to both models is also discussed (Fig.7.13).

The results for the frost heave and frost penetration obtained in theoretical calculations are in agreement with results obtained by numerical methods and in experimental investigations (Figs. 7.10 and 7.14), that allows utilization of the model for prediction and analysis of this phenomenon in the solution of practical problems (design and construction in North regions).

This book presents the study of freezing process in soil on the basis of the non-instantaneous kinetic model (Chapter 4). The solution of the considered problem is obtained by numerical methods. In this

respect, the author gives the analysis of both the stability of finite-difference scheme and convergence of the iteration process. An agreement of the results obtained by numerical solution and experimental profiles of the values is observed. In addition, an interesting and important result was obtained. According to the distributions, even at constant temperature values on the boundaries of the sample, under specific initial conditions, self-sustained oscillations can be obtained. This feature reflects cessation of monotonous movement of the phase front (dynamic instability) and results in segregate texture formation (Fig.4.7).

The results of the field (natural) experiments carried out by the author, treatment of the experimental data according to the “Likeness and Dimensionalities Theory”, numerical solution and comparison between theoretical and experimental results are given in Chapter 6. Here, the author describes the soils properties (loamy and sandy soils) of the areas and temperature behavior of permafrost. On the basis of the dimensionalities analysis, the dimensionless form for the treatment of the experimental results (complex dimensionless variables and criteria) was obtained.

By method of linear regression, the temperature distributions and phase front propagation are presented (Figs. 6.1-6.3) for considered types of soils. The analysis of theoretical results and their comparison with experimental distributions allows the utilization of the principles and functional dependences of the practical problems for prediction of the significant components of freezing and thawing soils in cold regions.

In conclusion, I would like once again to note that the structure of the book, the logical and clear interpretation of physical processes and results makes it comfortable for reading and using for practical work. All results of modeling represented in this book have an appropriate mathematical justification and are illustrated by comparison with experimental data.

I believe that the book will be interesting and useful for scientific researchers and also for engineering specialists working in design and construction in North regions.

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