Heat exchange of pipelines in the severe geo-cryological and hydrological ambient under macroclimatic and seasonal conditions

S.E.Kutukov

The heat&mass transfer of a transported product with embracing environment is a complex composite process, on which the determinate and statistical models for a omnifarious technological problem solutions of pipeline operating are created. Satisfactory outcomes of an individual solution of a pipeline Fluid Dynamics couldn't be obtained without a heat dissipating consideration inner and outer pipe. However, the transfer mechanisms and distinctive relaxation times inside and outside of the pipe are various insomuch that at the beginning of a pipeline transportation as branch L.S.Leibenzon has offered to part these problems on interior and exterior yet.

The thermal resistance of a ground embracing the pipeline is the limiting factor defining intensity of heat exchange of a transported product with an exterior environment in overwhelming majority of technological problems. An exception comprises only initial moment of the pipeline filling by a product. The first statements of a heat exchange problem, concerning with interaction of pipeline with a embracing ground massive refer to the end of past century. Consequently the textbook Forhgaimer-Greber and V.G.Shuhov solutions for a model stationary problem have appeared. Since some generations of the scientists have introduced the contribution to the given field of knowledge. V.I.Chernikin and I.A.Charny, A.A.Aronce and S.S.Kutateladzer, L.M.Altshuller and V.S.Yablonsky, P.I.Tugunov and V.F.Novoselov, L.N.Shchukin, L.N.Hrustalev, A.H.Mirzadganzader … - is far from being the complete list of the well-known scientists who have devoted their works to heat exchange of pipeline with an exterior environment.

Now the relevance of the problem has considerably been increasing in the context of the necessary monitoring of senescent pipeline systems in order to support their sufficient reliability and reason of omnifarious technological wiles for a operating efficiency raise, despite of a considerable drop of actual pipeline capacity.

Repeatedly it was noted the stationary temperature distribution along pipeline systems is unattainable under a design operating condition due to seasonal oscillations of climates. A seasonal ground freezing and a variation of pumping technological parameters do this problem non-stationary by definition. The heat exchange of the pipelines in permafrost can not be described even by a cyclical solution. The creation of rigorous three-dimensional non-stationary mathematical model for a heat dissipating from the pipeline in an environment is concerned with well-known methodological difficulties and considerable problems of its computer realization.

The greatest result in the heat exchange investigations of pipelines under the complicated operating conditions are come by prof. P.I.Tugunov's disciples. To detail a heat dissipating from a pipeline surface complicated by a permafrost destruction or a seasonal freezing - thawing of a ground the numerous experiments had been carried out by representatives of "HYDRAULICS" department of

USPTU, outcomes which were up in a basis of a creating of two-dimensional non-stationary heat exchange model of the pipeline in cryo-heterogeneous grounds.

It is necessary to mark key impossibility of physical modelling use in order to research of a system "pipeline - cryo-heterogeneous grounds" on small models. It is concerned with a contradiction of similitude time-parameters. Each of the operating factors superimposes on a time scale the requirements, which could be simultaneously fulfilled only at the equality of model and nature in size. However significance of laboratory experiment using an assay of the thermal interacting an electric heater with a ground in actual time scales and space for the development and the detailing of the model may be hardly overrated. Being set the different laws of a temperature modulation in time, the omnifarious situations on the various trace sites were imitated in the explicit non-stationary operating conditions. The analysis of the thermal field dynamics around the model pipeline has produced specification of heat dissipating in cryo-heterogeneous dispersible grounds, has revealed the distinctive features of heat exchange in the massive of a ground and on the daylight surface [1]:

$$\alpha_{эф} = \alpha_K + \Delta\alpha_W \exp\left\{-\frac{(x/2r_0)^2}{2\cdot\sigma^2}\right\},$$

Where x - distance along the ground surface from a tube axes up to a calculated point;

$\Delta\alpha_w$ - maximum exceeding of a heat-transfer coefficient from a surface of a ground above the algorithm manifold;

σ- parameter describing rate of a heat-transfer coefficient;

α_K - convective heat-transfer coefficient.

The parameters of the relationship are defined experimentally only for mineral grounds, however, a little bit diverse numerical values of the factors should be expected in peats bog without a key modification of form.

Comparison of obtained by experiment thermal conductivities and a solution of an inverse problem of a heat dissipating from a buried pipeline on the dispatcher list, have shown a considerable divergence of values. The thermal operating conditions of "non isothermal" pipeline built in modest climatic zone as well as pipeline sections in permafrost, waterlogged (slumpy) mineral and peat grounds were analysed. The checkpoints fixing temperature distributions of the ground massive in different moment of pipe exploitation are equipped on trunk pipeline (TPL)"Ozek-Suat-Grozny", "Gurjev-Kuibyshev", a permafrost trace section TKL "Urengoy-Surgut", blackoil pipeline "SOCK-Sterlitamack steam power plant", "NowOil - SPP-2" etc. The analysis of thermal field dynamic in the ground massive has revealed a multifaceted picture of heat exchange complicated by moisture migration. The drying effect is explicitly analyzed in zone of thermal influence of pipe [2]. The exhausting references for a choice of apparent ground conductivity are quoted on the basis of a data analysis of field ground trials and experience of pipeline maintenance, the wide experience of engineering geology, edaphology and soil mechanics are taken into account [3].

Diverse character of heat transfer was detected in waterlogged grounds having high-level of groundwater, that corresponds to pipeline sections built in slumpy, tundra, bottom grounds as well as in passages through aqueous barriers and in inshore shelf. A creation of three-dimensional non-stationary mathematical model conductive-convective heat&mass exchange in such grounds complicated by forced convection and filtration of moisture is an extremely difficult problem. The numerous experimental dates assembled at an actual stage of investigation have been worked over with correlative - regression methods for use in the technologic calculations of the pipeline systems [4]:

$$Ki = 0.848 \cdot (h_0/D)^{-0.05} \cdot (\lambda_0/\lambda_e)^{-0.08} + 1.896 \cdot (1.5 + h_{гв}/h_0)^{0.2} \cdot (1+Fo)^{-0.81},$$

Where Ki , Fo - parameters Kirpichjov, and Fourier accordingly;

h_0 - depth of a underlay up to an axes of the algorithm manifold;

$h_{гв}$ - stratification depth of groundwaters;

D - diameter of the algorithm manifold;

λ_0,λ_e - thermal conductivities of a dry ground and in the natural thermal condition accordingly.

However, the traditional method of heat balance with classic demarcation of interior and exterior heat exchange problems exhausted its capability. Only amplitudinous cybernetic modeling of heat&mass exchange process is capable to take into account all variety of the forms in particular emergence of its physical pattern. The non-stationary heat exchange modeling of the pipeline in the massive of a cryo-heterogeneous ground by finite-difference calculus allows taking into account the found effects out. The designed staffers of "Hydraulics and machinery" department of USPTU cybernetic model is founded on a system of the parabolic type nonlinear differential equations with effective heat transfer factors, time-varying and space being functions of temperature and properties of grounds [5]. In order to avoid a discontinuity on phase transition boundary of a ground moisture we are applying the integral transforms by Goodmen and Shamsudar - Sperrow. The algorithm is implemented by iterative methods under the implicit schema with equal weights on a five-nod pattern with a conformal mapping of calculated ground area to a rectangle. The temperature calculation along the third axis - length of the pipeline is realized by an integration of the differential thermal balance equation:

$$\frac{dT}{dx} = -\frac{\pi D \cdot Q(x,\tau)}{C_P \cdot G},$$

Since $Q(x,\tau)$ integrated heat flow rate from a surface of a length unit of the pipeline, defined by a solution of a two-dimensional problem;

πD - outside perimeter of the pipeline;

C_P - specific heat of a transported product;

G - instantaneous mass flow rate in the pipeline.

The calculation of temperature distribution dynamic by numerical integration of a heat balance equation has allowed to refuse the classic V.G.Shuhov's equation and, accordingly, to avoid using such a unsubstantiated lengthwise magnitudes as "temperature of a ground - T_0" and "a total heat transfer coefficient - K".

The modeling outcomes were repeatedly compared to experimental data obtained on laboratory stands, TKP "Urengoy-Surgut" and TGP "Urengoy-Chelyabinsk". An accuracy of thermal-hydraulic calculations was essentially improved, it is obtained for section of pipelines with low intensive heat exchange (Δt_{ev} = 2 … 20 ^{0}C) especially. The wide possibilities of optimization for the trunk pipeline operating are detected under non-stationary conditions with use of the local seasonal-climatic dynamics. The monitoring of pumping technology allows reducing the consequences of permafrost destruction due to the technogenic influence the pipeline onto an environment. The laboratory experiments reasoned restrictions of thawing aureole by basic principle at a particular cultural level of oil-gas-transport system operating in permafrost regions of a different ground constitution. The operating standing order for TPL "Tarasovskoye-Muravlenkovskoye" was justified by the numerical modeling [6].

For many years the stuff has been carrying out the fundamental researches in the background on hydromechanics and heat&mass transfer. At the same time we have been solving some problems for a raise of efficiency, reliability and ecological safety of systems. The new engineerings widely using in pipeline transportation are premiered by my colleagues. The prescriptions are designed and applied in TKP "Urengoy-Surgut", TPL "Tarasovskoye-Muravlenkovskoye", "Okha-Komsomolsk", "Urengoy-Chelyabinsk", "Gurjev-Kuibyshev", "Uzen-Shevchenko" etc. for increasing of efficiency of pipeline operating.

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The heat exchange of the pipeline is a background featured interacting of a pumped product with an environment for modeling all particular technological instances in problems of pipeline operating, but the modeling outcomes depend on its adequacy. Therefore the validity of some decisions of technological pumping-over control or design newly built or reconstructed pipelines are governed by its result.

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