SCIREA Journal of Physics

https://www.scirea.org/journal/Physics

December 17, 2019

Volume 4, Issue 6, December 2019

Heat-conductivity factor of the gas blanket on the surface of a centrifugal pump

Adib Akhmetnabievich Gareev

NIZHNESORTYMSKNEFT oil-and-gas production directorate, CES

SURGUTNEFTEGAZ PJSC, 1-14 Ul. Tyana, Nizhnesortymsky Settlement, Surgut Municipality, Tyumen Region, 628447, Russia.

E-mail: adibg@mail.ru

Abstract

Nowadays, the world is facing the depletion of developed reserves and exploitation of fields with poor reservoir features. These factors are forcing oil producers to use low-capacity electric centrifugal submersible pump units (ESP) with pumping pressure of over 2,000 m for oil extraction. The use of such ESP in oil production causes pump temperature to rise to about a hundred degrees centigrade. Increasing the temperature strength of the cable line, used as part of the ESP, reduces the number of failures in terms of the electrical component. However, the operation of a centrifugal pump at high temperatures leads to salt deposits on the pump's internal components. The theory and methodology of the struggle against salt deposits, as developed by the author of this paper, is described in the works [1-13] and the monograph [14]. The main point discussed in these works deals with identifying the thermal behavior of a centrifugal pump as a function of formation-fluid properties and the parameters of the pump itself. They show that centrifugal pump temperature during the pumping of highly-gassy fluids depends on a number of thermophysical properties of liquid-gas mixtures on the conventional border "surface of a pump's working components – layer of liquid-gas

mixtures on this surface" and on the heat-conducting properties of the oil-associated gas on the surface of the centrifugal pump. Since pump operation is accompanied by high pressure and fluctuating temperature, no laboratory research on said thermophysical properties has been conducted. This work is concerned with theoretical calculation of the heat-conductivity factor of the gas blanket on a centrifugal pump's surface. This investigation will allow for further development of the theory of a centrifugal pump's thermal behavior. The ability to calculate temperature depending on operating parameters and the flow characteristics of liquid-gas mixtures will provide for the introduction of automation in the monitoring of centrifugal pump behavior. Finally, the analytical review of the heat-conductivity factor of the gas blanket on a centrifugal pump's surface will enable us to create a program for controlling and preventing salt deposits inside the pump without the use of chemical treatments.

Keywords: oil production using electric centrifugal pumps, reduction in well-production rate, centrifugal pump heat-up, pump temperature, methane heat-conductivity factor, prevention of salt deposits.

1. Oil extraction using centrifugal pumps is the most commonly used method in the oil industry around the world. ESPs cover a wide capacity range, starting from 15 m3/day. What's more, this method is flexible and can be easily automated.

2. In recent years, developed reserves have started to become depleted, which is driving an increase in the number of wells equipped with low-capacity ESPs with pumping pressure of over 2,000 m. The operation of a low-capacity ESP in the "left branch of the head and rate" leads to the loss of centrifugal pump efficiency. Proportion of energy applied to the pump: 1 - efficiency, converts into heat. Heat release in a centrifugal pump causes its temperature to rise.

3. Pump temperature rise as a function of the parameters of the pumped liquid-gas mixture and ESP specifications was discussed in the works [8 - 12], which proved that said temperature rise causes a so-called "associated-water boiling" effect in the pump. The boiling of associated water is inherently accompanied by scale formation on the surface of the heat-flow source, i.e. on the surface of the ESP's working components.

4. Thus, the study of the ESP's temperature condition as a function of process parameters and the properties of the pumped fluid encapsulates the main problem associated with the operation of complicated well stocks equipped with low-capacity pumps. Very often, low-capacity ESPs run on the verge of pump starvation, i.e. under conditions where the head generated by the ESP barely exceeds hydrostatic pressure at the ESP level. In this case, intake pressure is less than saturation pressure and gas content in the liquid-gas mixture is such that the efficiency factor is minimal.

5. The approximate solution to the problem of the centrifugal pump's thermal condition as a function of process parameters (under conditions nearing pump starvation) is described in [3], and is written as:

$$\Delta T_w = T_w - T_f = \frac{\varphi}{1-\varphi}\frac{q_0 R_2 P_{нас} P_{пр}}{2(1-B)h\Gamma\Gamma_{ат}}\left\{\frac{1}{\alpha}+\frac{\delta_{из}}{\lambda_{из}}\right\} \quad (1)$$

where T_w - temperature inside the pump housing, T_f - temperature of the liquid-gas mixture on the intake side, R_2 - radius of the pump cylindrical housing (0.05 m), $P_{нас}$ - bubble-point pressure (atm), Γ - reservoir gas-oil ratio (m^3/m^3), h - pump head (atm) with free gas φ in the mixture (fraction), $\delta_{из}$ - thickness of gas bubbles on the pump surface (about 0.002-5 m), B – water content in the production stream, in fractions (less than 0.98), $\lambda_{из}$ - gas blanket heat conductivity on the pump housing surface (W/(m*K)), α - convection heat-transfer coefficient (W/(m^2*K)) in the labyrinths of pump elements with respect to the liquid-gas mixture, q_0 - heat-source power density per one running pump (W/m^3), P_{am} .- atmospheric pressure (atm). Investigations of the annular space between the ESP and the flow spring from the pump intake to the dynamic level are described in the works [6, 11, 12]. It has been shown that, in the course of ESP start and its setting to operating cycle, said space is gradually replaced by oil. During this time interval, the surface of the centrifugal pump and flow column do not corrode – even when running at temperatures exceeding the working temperature of updated cable lines (230^{0}C).

6. If an ESP is running at a temperature far above that of the reservoir liquid-gas mixture, the outer surface of the pump will always become covered with gas bubbles, whose heat conductivity is much less than the heat-conductivity factor of oil or water (let alone that of the metal pump housing). Therefore, pump temperature greatly depends on the thermophysical properties of the gas bubbles forming on its surface. There are no reports on

any studies of the condition and thickness of the gas-bubble layer on an ESP's surface during its operation in near-starvation mode in specialized scientific-and- technical literature. There are fragmented investigations of the heat-absorption capacity and heat conductivity of gases and liquids under pressures below 1 MPa. At ESP intake, pressure fluctuates in the range of 3...20 MPa or even higher, and under such conditions, the formation, growth and detachment of gas bubbles on heat-emitting surfaces (like the centrifugal pump's surface) remain unknown.

7. The goal of this work is to further study the properties of gas bubbles on heat-emitting surfaces and to attempt to create a mathematical model for the heat-conductivity factor of the gas blanket on a centrifugal pump's surface as a function of well-operation parameters and reservoir-fluid properties.

As shown in the studies [12], gas bubbles on a centrifugal pump's surface occur in microscopic cavities, where low-pressure (pressure-drop) areas always exist under the action of surface repulsion forces. The formation and growth of water-vapor bubbles is a rather well-studied phenomenon. The similar effect of the formation of free gas bubbles on the surfaces of downhole equipment and rock debris drifting in the oil flow is described in the works [1, 15, 17]. Moving to a statement of the problem, let's first take a look at some of the parameters and properties of associated gas.

1) Bubble-point pressure and gas-factor values, by field, are shown in Table 1.

Таблица 1. / Table 1.

Месторождения	Газовый фактор, м3/м3	Удельный вес сепарированной нефти, т/м3	Давление насыщения, атм	$T_{пласта}$, ^0C	Содержание метана в нефтяном газе, %
Oil field	Gas factor, m3/m3	Relative weight of liberated oil, t/m^3	Bubble-point pressure, atm	$T_{reservoir}$, ^0C	Methane content in wellhead gas, %
Месторождение 1 / Field 1	51	0.86	78	76	66
Месторождение 2 / Field 2	112	0.86	105	74	72

Месторождение 3 / Field 3	71	0.854	93	76	76
Месторождение 4 / Field 4	59	0.85	77	73	91
Месторождение 5 / Field 5	140	0.83	134	79	85
Месторождение 6 / Field 6	110	0.82	142	79	88
Месторождение 7 / Field 7	66	0.844	84	77	61

Состав попутного газа по некоторым месторождениям приведен на таблице 2. /

Associated-gas composition at some fields is shown in Table 2.

Таблица 2. / Table 2.

Месторождения / Field	Состав газа в % / Gas composition, %			
	Метан / Methane	Этан / Ethane	Пропан / Propane	CO_2
Месторождение А / Field A	83	6	10	0.7
Месторождение В / Field B	84	3	5	0.53
Месторождение К / Field K	80	11	10	1.75

As you can see in Table 2, many associated gases are 82% methane; the rest of the gases, like ethane and propane, average about 17% methane content. To simplify further reasoning, let's assume that associated gas consists of pure methane. By doing so, we'll slightly sacrifice the accuracy of our calculations; however, we'll be able to estimate the error theoretically in the course of studying the problem.

In order to simplify the automatic calculation of the pump surface's temperature, let's represent the formula for the heat conductivity of the gas blanket on a centrifugal pump's surface by way of empirical dependence.

8.Elementary kinetic model of the gas-heat conductivity theory at atmospheric pressure.

Gas is constantly affected by shear forces, which cause some volumetric flow. Hence, at any point, a space-velocity vector is added to the eigenvector of disordered molecular motion. The transfer of motion from one molecule to the other is essentially a heat-transfer cycle.

Heat-transfer speed is characterized by the heat-conductivity factor, calculated by the formula [16]:

$$\lambda = \frac{\upsilon L C_\upsilon n}{3} = (const)\frac{T^{1/2}}{M^{1/2}\sigma^2} \qquad (2)$$

T - gas temperature, K; M - molecular mass; σ - hard sphere radius, $\dot{A}$; L - mean free path length of molecules; υ - molecule average speed; C_υ - specific heat at constant volume; n - molecule density (number of molecules per 1 cu cm);

For monoatomic gases, which have no rotational or vibrational degrees of freedom, the heat-conductivity factor is:

$$\lambda = \frac{1{,}989 * 10^{-4}(T/M)^{1/2}}{\sigma^2 \Omega_\upsilon} \qquad (3)$$

where Ω - collision interval, non-dimensional (normally equal to 1);

For methane, naphthenes and aromatics at $T_r < 1$

$$\lambda = 4{,}54 * 10^{-6} T_r \frac{C_p}{\Gamma} \qquad (4)$$

For all other hydrocarbons and other reference temperature ranges:

$$\lambda = (10^{-6})(14.52T_r - 5{,}14)^{2/3}\frac{C_p}{\Gamma} \quad \text{(cal/(cm*s*K)} \qquad (5)$$

$$\Gamma = \frac{T_c^{1/6} M^{1/2}}{P_c^{2/3}} \qquad (6)$$

where: C_p - gas molar-heat capacity, cal/(mole*K); T_r - gas relative temperature (gas temperature divided by critical temperature); T_c - gas critical temperature; P_c - gas critical pressure, atm;

9. Effect of temperature and pressure on gas heat conductivity under low pressure.

The heat conductivity of gases under low pressure increases with a rise in temperature – molecule average speed goes up, collision interval goes down.

The volume $d\lambda / dT$ changes from $0.1*10^{-6}$ to $0.3*10^{-6}$ cal/(cm*s*K^2).

Owen and Todos [16] have determined the proportional dependency of heat-conductivity change under low pressure, as described by the following formula:

$$\frac{\lambda_{T_2}}{\lambda_{T_1}} = \left(\frac{T_2}{T_1}\right)^n \qquad (7)$$

and by experiment determined the value n=1.786.

Many high-pressure heat-conductivity correlations existing near an electric centrifugal pump's surface can be determined using the principle of corresponding conditions, whereby either λ/λ_0, or λ/λ_c is plotted on a reduced-pressure function graph at constant reduced temperature. Heat conductivity at T and low pressure is designated by λ_0, λ_c - heat conductivity value at T_c (critical temperature) and under P_c (critical pressure). The graphs $\lambda/\lambda_0 = f(P_r)$ were plotted by Steel and Todos (Figure 1)

10. Methane-gas heat conductivity under high pressure and at high temperature near a centrifugal pump.

Many high-pressure heat-conductivity correlations are based [2, 16] on the principle of corresponding conditions, whereby either λ/λ^0, or λ/λ_c is plotted on a reduced-pressure function chart at constant reduced temperature.

Let's denote heat conductivity at temperature T^0 and under low pressure by λ^0, and heat conductivity at critical temperature T_c and under critical pressure P_c by λ_c

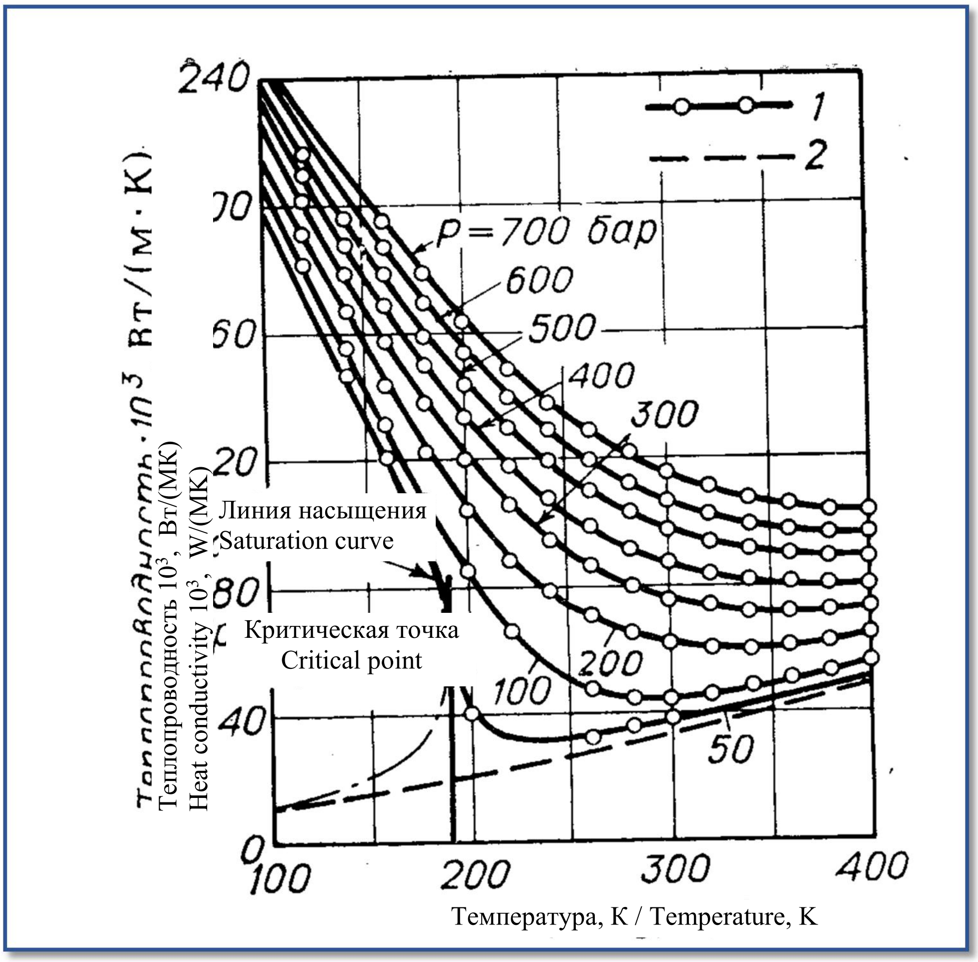

Figure 1. Dependency of methane heat conductivity on temperature and pressure.

1 – Heat-conductivity development curve as a function of temperature and pressure.

2 – asymptotic value of the heat-conductivity factor under the pressure of 1 atm. (P_c - 45 bar)

(Taken from the book "Properties of Gases and Liquids" [17]).

The dependency of "excessive heat conductivity" on methane density, shown in Figure 1, is a matter of our practical interest. The graph was plotted by N. Mani and J.E.S. Venard [16] on the basis of experimental results. Methane heat conductivity under specific pressure and at specific temperature can be determined according to this graph.

Experimental values of the heat-conductivity factor are shown in Table 1.

Таблица 1. / Table 1.

T^0K	$\lambda*10^{-3}$ (W)/(m*K), under $P*10^5$			
	P=1	P=100	P=300	P=500
300	34.2	44.7	74	96

400	49.3	55.8	72.3	88
600	88.8	92.6	102	110
750	118	121	127	135

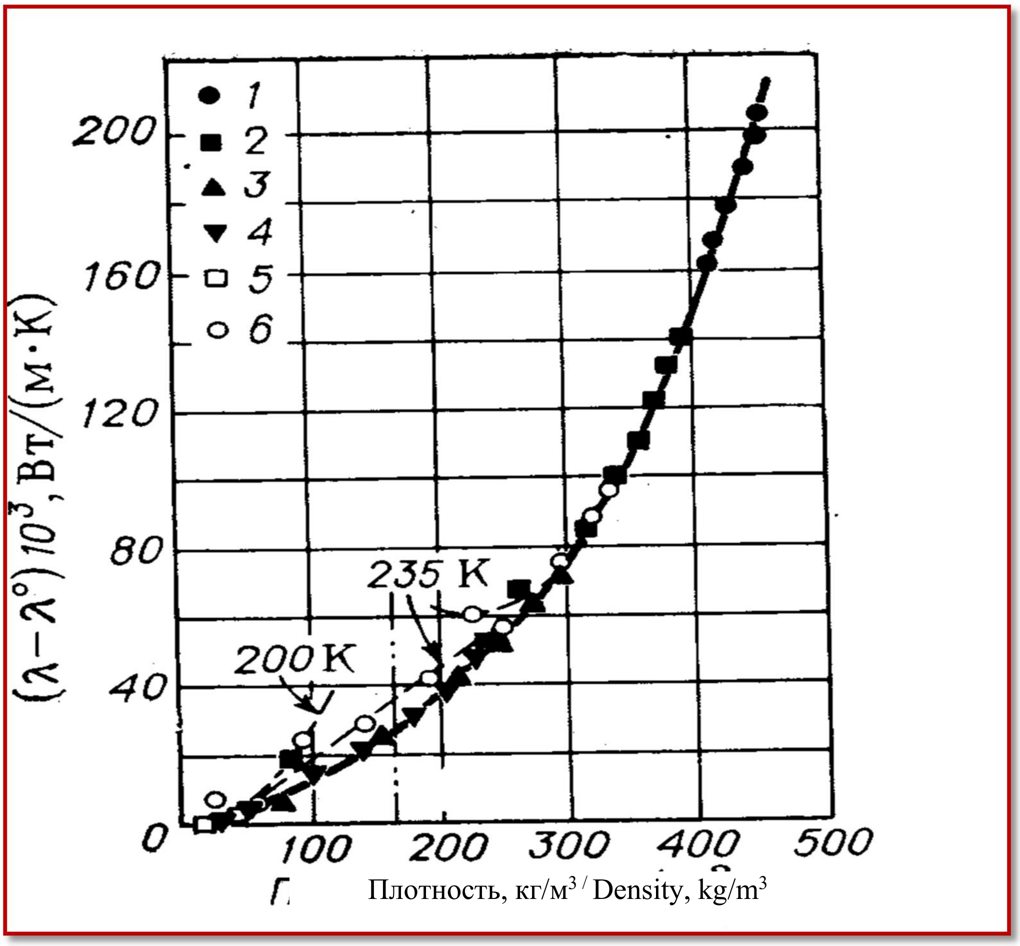

Figure 2. Methane "excessive heat conductivity - density"

1 – at the temperature of 120 ^{0}K, 2 – at 200 ^{0}K, 3 – 300 ^{0}K, 4 – 400 ^{0}K, 5 – 200 ^{0}K, 6 – 235 ^{0}K.

(Taken from the book "Properties of Gases and Liquids" [16]).

As you can see in Graph 2, the difference in heat conductivity $(\lambda - \lambda^0)$ is expressed as a function of density.

Approximate analytic expressions for the curve in the Figure take the following form:

$$(\lambda - \lambda^0) * \Gamma * Z_c^5 = (14,0 * 10^{-8})(e^{0,535\rho_r} - 1) \text{ при/at } \rho_r < 0,5 \qquad (8)$$

$$(\lambda - \lambda^0) * \Gamma * Z_c^5 = (13,1 * 10^{-8})(e^{0,67\rho_r} - 1,069) \text{ при/at } 0.5 < \rho_r < 2 \qquad (9)$$

$$(\lambda - \lambda^0) * \Gamma * Z_c^5 = (2{,}976 * 10^{-8})(e^{1{,}115\,\rho_r} + 2{,}016) \quad \text{при/at} \quad 2{,}0 < \rho_r < 2{,}8 \quad (10)$$

$$\Gamma = \frac{T_c^{1/6} M^{1/2}}{P_c^{2/3}} \quad \rho_r = \frac{\rho}{\rho_c} \quad (11)$$

ρ - gas density, ρ_c - critical density, ρ_r - gas relative density.

To determine $\lambda - \lambda^0$ in case of nonpolar gases (natural gases), the correlation shown in Figure 3 is used.

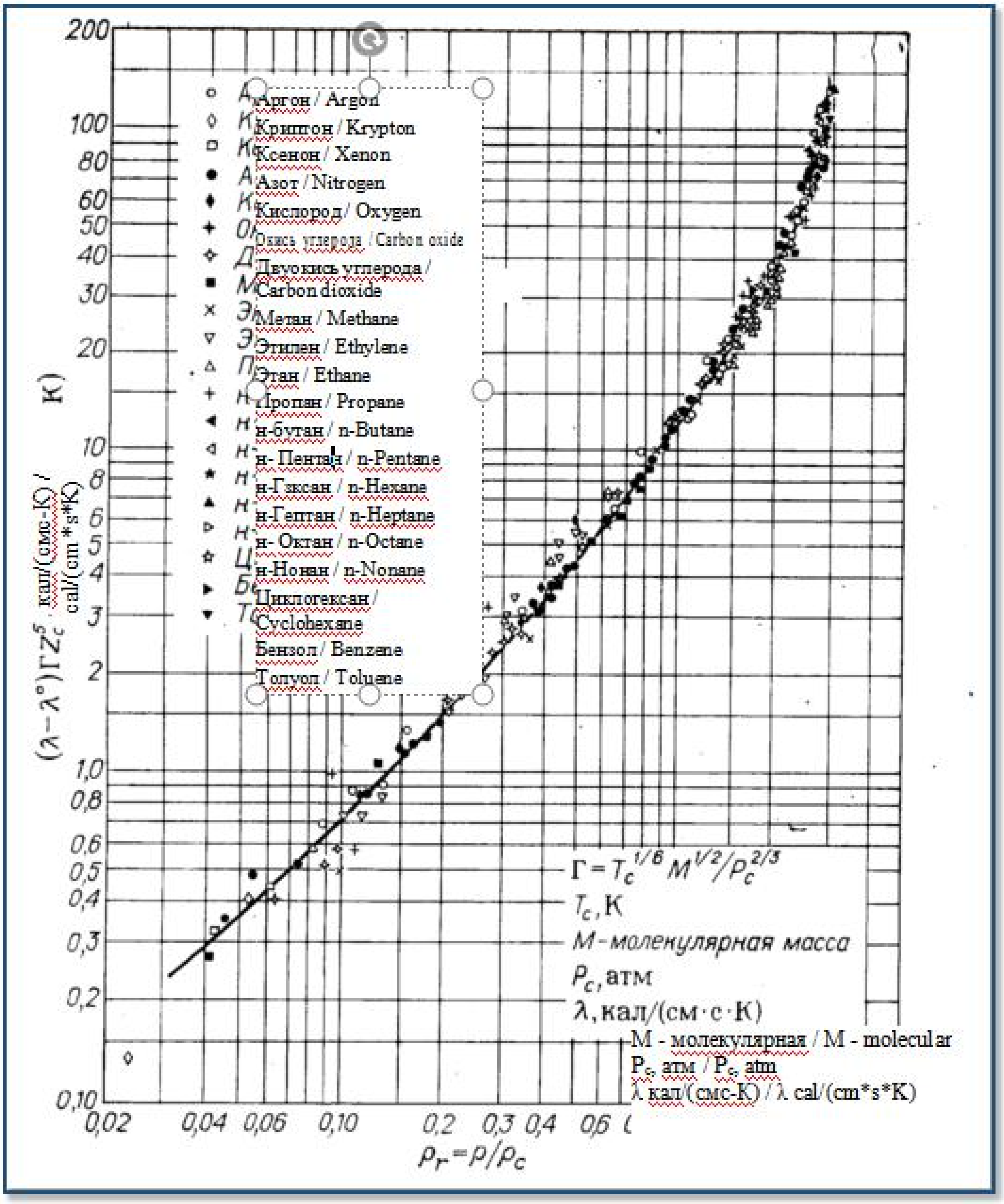

Figure 3. Steel & Todos' correlation for the identification of tight gases.

(Taken from the book "Properties of Gases and Liquids" [16]).

11. Let's consider the calculation of the methane heat-conductivity factor under the following conditions: pressure P=100 atm, temperature = 300^0K, experimental heat-conductivity factor value is $\lambda_{300} = 34,2*10^{-3} \frac{вт}{м*К}$ at the temperature of 300^0K and under $P = 1атм$; methane critical temperature is 190^0K, critical pressure P_c=45.4 atm. As you can see in the Table [2], methane molecular mass M=16 g/mole, methane critical volume is $V_c = 99 \frac{см^3}{моль}$ and critical z-factor is 0.228.

Let's calculate the G-factor:

$$\varGamma = \frac{T_c^{1/6} M^{1/2}}{P_c^{2/3}} = \frac{190^{1/6} 16^{1/2}}{45,4^{2/3}} = 0,75361$$

Let's calculate the volume of methane at the temperature of 300 0K and under the pressure of 100 atm:

$$V = \frac{ZRT}{P} = \frac{(0.228)*(82.07)*300}{100} = 56,13 \frac{см^3}{моль}$$

Let's calculate the relative density of methane:

$$\rho_r = \frac{V_c}{V} = \frac{99}{56,13} = 1.764$$

According to the graph shown in Figure 3, at $\rho_r = 1.764$ using the formula (9), we get:

$$(\lambda - \lambda^0) * \varGamma * Z_c^5 = (13,1*10^{-8})(e^{0,67\rho_r} - 1,069)$$

и далее: / and further:

$$(\lambda - \lambda^0) * \varGamma * Z_c^5 = (13,1*10^{-8})(e^{0,67*1,764} - 1,069) = 2,79175 * 10^{-7}$$

Находим: / We find:

$$(\lambda - \lambda^0) = \frac{2,79175*10^{-7}}{\varGamma * Z_c^5} = \frac{2,8*10^{-7}}{0.75361*0.228^5} = 0.000042 \text{ (кал/(см*с*К) / (cal/(cm*s*K)}$$

В системе СИ: / in SI units:

$$(\lambda - \lambda^0) = 0,000045 \frac{кал}{см*с*К} = 0,0000045 \frac{ккал}{м*с*К} = 4186,8*0,0000045 = 0,019 \frac{вт}{м*К}$$

Значение теплоемкости при температуре 300^0К и давлении 100 атм: /

Heat conductivity value at the temperature of 300^0K and under the pressure of 100 atm:

$$\lambda = \lambda^0 + 0{,}019 \frac{вт}{м*К} = (34{,}2*10^{-3} + 19*10^{-3}) \frac{вт}{м*К} = 53{,}2 \frac{вт}{м*К}$$

По справочнику находим, что при температуре 300^0К и давлении 100 атм коэффициент теплопроводности метана равен /

Using the reference manual, we find that at the temperature of 300^0K and under the pressure of 100 atm, the heat-conductivity factor is

$$\lambda\Big|_{p=100} = 44{,}7 \frac{вт}{м*К}$$

Относительная ошибка при этом составляет: /

That said, the relative error will amount to:

$$\Delta\lambda = \frac{53{,}2 - 44{,}7}{44{,}7} = 19\%$$

Under relatively high pressure (300 atm), the methane heat-conductivity factor will differ from the experimental value by 19%.

It is possible to demonstrate by calculations that under the pressure found at an electric centrifugal pump's intake, the relative error of the result, calculated by the formula (9-10), is less than 5%.

The largest difference between the methane heat-conductivity factor and the one calculated near the critical point is registered at the point with the coordinates: $T_c = 190^0 C$ $(t^0 C = 190 - 273 = -83)$ and under the pressure of $P_c = 45.4 атм$.

The methane condition point with the coordinates $P_c 45.4 атм$ and $T_c = -83^0 C$ is not typical for an electric centrifugal pump; therefore, the calculation of methane heat conductivity can be performed according to (9 – 10) using reference data for molecular weight and critical values. The relative error in this case will not exceed 5%.

Similarly, it is possible to compile a table of methane heat conductivity under conditions approximating the real operating conditions of an electric centrifugal pump. In this case, pump temperature fluctuates within the range between the liquid-gas temperature at the pump intake and the working temperature of the cable extensions (its flat portion), which amounts to about 580 ^{0}K. Pressure at the pump intake fluctuates from 3 MPa to 7 MPa.

T^0K	$\lambda * 10^3\ Bm/(м * K)$ при p, Мпа / $\lambda * 10^3\ Bm/(м * K)$ under p, MPa								
	2 Мпа / 2 MPa			3 Мпа / 3 MPa			5 Мпа / 5 MPa		
	$\lambda_{изм}$	$\lambda_{вычис}$	$\Delta\varepsilon\%$	$\lambda_{изм}$	$\lambda_{вычис}$	$\Delta\varepsilon\%$	$\lambda_{изм}$	$\lambda_{вычис}$	$\Delta\varepsilon\%$
320	38.4	38.42	0.05	39.2	39.3	0.25	41.1	41.3	0.48
340	41.2	41.23	0.07	42	42.1	0.23	43.7	43.85	0.34
360	44.2	44.23	0.07	44.9	44.99	0.2	46.5	46.9	0.85
400	50.5	50.6	0.09	51.1	51.4	0.58	52.5	52.9	0.75
450	58.9	59.19	0.33	59.5	59.8	0.51	60.7	61.1	0.65
500	67.9	67.95	0.07	68.4	68.49	0.13	69.5	70.2	0.997
550	77.3	77.8	0.12	77.8	77.95	0.19	78.8	79.5	0.88

where:

1. $\lambda_{изм}$ - measured heat-conductivity factor value;

2. $\lambda_{вычис}$ - heat-conductivity factor value, calculated by the method described above;

3. $\Delta\varepsilon\%$ - relative error, as a percent.

Performed calculations of the heat-conductivity factor and relative errors thereof confirm the acceptable convergence of the Steel & Todos correlation technique.

It is highly recommended to use this technique in further calculations of the methane heat-conductivity factor on an electric centrifugal pump's surface.

Thus, we have shown that it is possible to determine the liberated-gas heat-conductivity factor on an electric centrifugal pump's surface during pump operation. The value of the methane heat-conductivity factor near the critical point changes only slightly, fluctuating within the range of from 0.032 to 0.044 $\frac{вт}{м * K}$. For approximate calculations, we can assume that the methane heat-conductivity factor is constant.

Conclusions:

1) The temperature of an electric centrifugal pump during oil extraction depends on oil flow characteristics and the technical parameters of the pump.

2) Operation of a centrifugal pump with intake pressure below bubble-point pressure leads to a rise in pump temperature.

3) Heat development and transfer inside a centrifugal pump depend on the heat-transfer factor and the heat-conductivity factor of the gas covering the pump's outer surface.

4) The heat-conductivity factor of the liberated associated gas on the pump's surface can be assumed as the methane heat-conductivity factor.

5) The ability to calculate methane heat-conductivity factor will enable the forecasting of pump temperature during changes in operating mode.

6) For the simplified calculation of pump temperature, it is possible to assume that the methane heat-conductivity factor does not depend on temperature.

REFERENCES

[1] A.A. Aleksandrov, B.A. Grigoryev Thermal and Physical Properties of Water and Water Vapor/ M. MEI Publishing Company. 1998, pg. 423

[2] N.B. Vargaftik, L.P. Fillipov, A.A. Tarzimanov, E.E. Trotsky Reference Guide on the Heat Conductivity of Liquids and Gases. M. Energoizdat, 1990, pg. 352

[3] A.A. Gareyev Regarding the significance of thermal condition in electric centrifugal pump units (ESP). “Oborudovaniye i tekhnologii dlya neftegazovogo kompleksa” (Equipment and Technologies for the Oil & Gas Sector), 2009, No. 1.

[4] A.A. Gareyev Regarding maximum-permissible gas content at centrifugal pump intake. “Oborudovaniye i tekhnologii dlya neftegazovogo kompleksa” (Equipment and Technologies for the Oil & Gas Sector), 2009, No. 2.

[5] A.A. Gareyev. Mathematical modeling of problems occurring during the operation of ESP with fluctuating pump-shaft load. Automation, telemetry and communication in the oil industry: NTZh, 2010, No. 3.

[6] A.A. Gareyev. Regarding the gas-separation factor at pump intake. Neftyanoye khozyaistvo, 2010, No. 6, pp. 90-93. - pp.40-45.

[7] A.A. Gareyev Effect of centrifugal pump efficiency on its thermal behavior. A.A. Gareyev, K.R.Urazakov"Oborudovaniye i tekhnologii dlya neftegazovogo kompleksa" (Equipment and Technologies for the Oil & Gas Sector), 2010, No. 5, pp. 21-24.

[8] A.A. Gareyev Regarding the thermal behavior of electric submersible pumps. "Oborudovaniye i tekhnologii dlya neftegazovogo kompleksa" (Equipment and Technologies for the Oil & Gas Sector). 2010, No. 6, pp. 35-41.

[9] A.A. Gareyev Regarding the thermal behavior and thermal shock phenomenon of electric centrifugal pumps (as a matter for discussion). Neftyanoye khozyaistvo, 2011, No. 3, pp. 122-126.

[10] A.A. Gareyev. Regarding the significance of pressure at electric centrifugal-pump intake / A.A. Gareyev, R.F. Sharafutdinov, R.A. Valiullin Neftyanoye khozyaistvo, 2012, No. 10, pp. 128-131.

[11] A.A. Gareyev Calculation of gas-separation factor at pump intake. Neftyanoye khozyaistvo (electronic version), 2013, No. 3, pp. 82-85.

[12] A.A. Gareyev Regarding the salt-deposition mechanism. "Neftepromyslovoye delo" (Oilfield Engineering) NTZh, 2017, No. 4, pp. 35-45.

[13] A.A. Gareyev Techniques for electric centrifugal-pump operation without salt deposition (task description) "Oborudovaniye i tekhnologii dlya neftegazovogo kompleksa" (Equipment and Technologies for the Oil & Gas Sector), 2018, No. 3, pp. 27-31.

[14] A.A. Gareyev Current problems of low-capacity electric centrifugal-pump operation during oil extraction. Printing and Publications Center, Bashkir State University. 2013.

[15] D.A. Labuntsov Physical fundamentals of power engineering. M. MEI Publishing Company, 2000, pg. 388.

[16] R. Reid, J. Prausnitz, T. Sherwood The Properties of Gases and Liquids Translated from English by B.I. Sokolova. Leningrad "Khimiya" (Chemistry), Leningrad Division. 1982, pg. 592

[17] F.F. Tsvetkov, B.A. Grigoryev Heat and mass transfer. M. MEI Publishing Company. 2006, pg. 545