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Investigation of Heat Exchange Processes in the Oil Well

Bulchayev N.D.
Institute of Oil and Gas
Grozny State Oil Technical University
named after acad. M.D. Millionshchikov,
Grozny, Russia,
nbulchaev@yandex.ru

Khaladov A.Sh.
Institute of Oil and Gas
Grozny State Oil Technical University
named after acad. M.D. Millionshchikov,
Grozny, Russia
haladov_a_sh@mail.ru

Gairabekov I.G.
Faculty of Civil Engineering
Grozny State Oil Technical University
named after acad. M.D. Millionshchikov,
KNII RAS,
Grozny, Russia
ibragim.ggni@mail.ru

Mollaev R.Kh.
Institute of Oil and Gas
Grozny State Oil Technical University
named after acad. M.D. Millionshchikov,
Grozny, Russia
rusl.molaev@ yandex.ru

Abumuslimov A.S.
Faculty of Civil Engineering
Grozny State Oil Technical University named after acad. M.D. Millionshchikov,
Grozny, Russia
adam290692@mail.ru

***Abstract* – In the practice of pumping oil wells, thermo-boric conditions occurring inside the well are important. The neglect(or omission) of heat exchange processes occurring in the well may lead to a decrease in the performance of pumping equipment, reduced turnaround time and accidental failures of downhole equipment. In this paper, on the basis of the obtained theoretical and experimental conclusions made by well-known experts in the field of hydromechanics and thermodynamics, the issues of heat exchange processes occurring inside an operating well are considered. The heat transfer for a mixture of water - feldspar particles with a turbulent mode of motion in the annular space is investigated. The combined effect of the particle size on the heat transfer coefficient, the hydraulic diameter of the annular space, the ratio of the hydraulic diameter to the average particle diameter, the concentration of particles in the mixture, the Prandtl and Reynolds numbers is experimentally shown. It has been established that omission of the influence of a mechanical impurity in determining the heat exchange coefficient may lead to its understating more than 2 times, and the temperature of the electric motor - by 10 °C. The selection of the technological parameters of the operation of the ESP in such a way that the value of dp falls within the interval from 2 to 6 will help improve heat exchange and protect the electro motor from overheating.**

Keywords – turbulent mixing; dimensionless parameter; boundary layer; particle degree of freedom; approximation of averages.

I. INTRODUCTION

Based on the obtained theoretical and experimental conclusions and conclusions made by well-known experts in the field of hydromechanics and thermodynamics, the issues of heat exchange processes occurring inside an operating well are considered. The heat exchange for a mixture of water-particles of feldspar with a turbulent mode of motion in the annular space is investigated.

The combined effect on the heat exchange coefficient of the particle size, the hydraulic diameter of the annular space, the ratio of the hydraulic diameter to the average particle diameter, the concentration of particles in the mixture, the Prandtl and Reynolds numbers is shown.

In the works of S.A. Brandon (1970) and R. Zisselmar (1979) it was noted that a strong interaction between the fluid and the solid phase can cause turbulent mixing [1, 2]. In this case, the heat exchange from the suspension wall is improved, which is achieved by reducing the viscous boundary layer (formed in the near-wall area of the SEM), inside which the temperature changes dramatically in contrast to the flow core, over the cross-section area of which the temperature of the suspension practically does not change.

II. MAIN BODY

The paper presents a dimensionless parameter that allows to establish the dependence of the diameter of the well on the diameter of the submersible pump and the Reynols number (1)

$$dp = (dp/Dh)^{11/16}Rem, \quad (1)$$

where dp is the internal diameter of the production string, m; Dh - diameter of the SEM, m; Rem = Dhumρm / µm is the Reynolds number for the mixture; um — mixture rate, m / s; ρm = φρp + (1-φ) ρl - the average density of the mixture, kg / m³; φ - local volumetric content of particles, de; ρp - particle density, kg / m³; ρl is the density of the liquid, kg / m³; µm is the average viscosity of the mixture, Pa · s (Па · с) .

Experiments have shown that at dp = 4.4 for a suspension of type glass powder, the maximum heat exchange coefficient is observed [2–4].

The heat exchange for a mixture of water - feldspar particles with a turbulent mode of motion in the annular space is investigated. The combined effect of the particle size on the heat transfer coefficient, the hydraulic diameter of the annular space, the ratio of the hydraulic diameter to the average particle diameter, the concentration of particles in the mixture, the Prandtl and Reynolds numbers is experimentally shown. Fig. 1 shows the experimental dependence of the relative increase in heat transfer coefficient (hs / hsw – 1) · 100 (hs is the heat exchange coefficient for the flow of water-particle mixture of feldspar in the annular space, W · K / m²; hsw is the heat exchange coefficient for single-phase water flow in the annular space, W · K / m²) of the dimensionless parameter dp, determined by the relation (1).

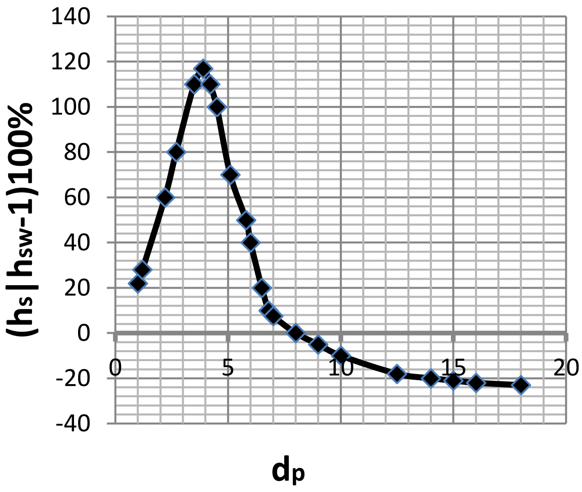

Fig. 1. The result of the approximation of the experimental values of the heat exchange coefficient for the water-particle mixture of feldspar by the Lorentz function d_p.

As can be seen from Figure 1., with a certain combination of the above parameters, the heat exchange coefficient for the mixture can reach values exceeding the values for a single-phase flow more than two times [4].

Thus, the neglect of mechanical impurities in the model of heat transfer between the SEM and the sand-liquid mixture can lead to errors in the calculation of the heat transfer coefficient of more than 2 times.

The explanation of such the parameter (hs / hsw– 1) 100 on the graph can be as follows. With average values of Rem and high particle concentrations, the radial particle distribution function (RFSP) becomes steady(even), i.e. the mixture in the annular space has a stable homogeneity. The interaction of particles with each other and with turbulent vortices can suppress the turbulent flow regime and, as a result, reduce the hs / hsw ratio to a minimum. However, an increase in the density of the mixture ρm to some extent may contribute to heat transfer by reducing the thickness of the viscous boundary layer, the cause of which is an increase in the interaction of solid particles with the wall. In such conditions, the degree of freedom of movement of particles decreases in the radial direction.

A sufficiently significant factor for heat exchange processes is the specific heat capacities of the liquid and mechanical particles. With an increase in the concentration of mechanical impurities, the heat capacity of the mixture becomes lower than that of water, since the heat capacity of feldspar particles is about 5 times less than the heat capacity of water [5, 6].

At low values of Rem and a small concentration of particles, (the mode of motion remains turbulent), the effect of RFP on heat exchange becomes more significant. Experimental data [7] showed that the content of particles near the wall of the EMP is less than that of the wall of the production string with an upward flow of the mixture. This means that solid particles located near the inner wall of the annular gap have a greater degree of freedom to interact with the wall, which reduces the thickness of the boundary layer. This circumstance will stimulate the process of heat exchange, as it passes through the inner wall of the annular gap. The counteraction of these two effects (interaction of particles with the wall and changes in the heat capacity of the mixture) increase in the heat transfer coefficient hs / hsw will vary depending on the density of the mixture and the radial distribution of particles. At high values of Rem, the parameter (hs / hsw – 1) · 100 decreases, since solid particles acquire a rather large impulse in the direction of flow. In this case, the radial motion of the particles is suppressed, and the thickness of the viscous boundary layer no longer decreases due to the interaction of the particles with the wall. This effect may disappear due to an increase in particle concentration, which will lead to more intense collisions of particles with the wall. The parameter (hs / hsw– 1) · 100 will increase again with an increase in the Reynolds number, especially at relatively high concentrations of small and medium particles, which are easily addicted to vortices, which has a positive effect on the heat exchange process. Larger particles will again suppress the turbulent flow regime even at high Reynolds numbers.

To simulate heat transfer, the density and heat capacity of the mixture must be averaged over the volume and mass content of particles according to the formulas [8]:

$$\rho m = \rho l(1-\varphi) + \rho p\varphi \quad (2)$$

$$Cm = Cl(1-X) + CpX, \quad (3)$$

where Cm, Cl, Cp - specific heat capacity of the mixture, liquid and particles, j / (kg / K), respectively; X is the local mass content of particles, DE

To calculate the viscosity and thermal conductivity coefficient Kofanov (1964) and Smith (1982) [5] recommend the following ratio:

μm = μl(1+2,5φ + 7,17φ² + 16,2φ³), (4)

km =kl [2kl + kp - 2φ(kl-kp)] /[2kl + kp + φ(kl-kp)], (5)

where μl, kl, accordingly, the viscosity (Pa· s) and thermal conductivity (W / (m· K)) of the liquid; km - thermal conductivity of the sand-liquid mixture, W / (m· K); cr is the thermal conductivity of the particle, W / (m· K).

Using the above ratios, we calculate the heat transfer coefficient for any flow regime. For the turbulent flow regime, it is necessary to take into account the interactions of solid particles with a viscous boundary layer.

For the flow of a liquid without mechanical impurities, the heat exchange coefficient is determined from the Nusselt number, which is calculated from the Petukhov-Rosen ratio [6]:

$$\mathrm{Nul} = \frac{f/8(\mathrm{Rel}-1000)\cdot \mathrm{Prl}\,(086)\cdot(\mathrm{Dm}/\mathrm{D\,c})^{-0,16}}{(1+12{,}7(f/8)^{1/2})\cdot(\mathrm{Prl}^{2/3}-1)\,,}\,, \quad (6)$$

where Rel = Dhulρl / μl; Prl = Clμl / kl; Cl, kl, μl, ρl are respectively the heat capacity (J / (kg • K)), thermal conductivity (W / (m • K)), dynamic viscosity (Pa • s) and density (kg / m³) fluid excluding mechanical impurities.

Accounting for the influence of the interaction of particles with the boundary layer is taken into account using the equation [7]:

$$y = yo + 2Aw\,\pi\,(4(x - xc)^2 + w^2), \quad (7)$$

where y = (hs/hsw– 1) ·100; x = dp; yo = -25,85; xc=3,90; w = 3,89; A = 878,49.

Expressing the ratio hs / hsw as a function of dp from equation (7) and multiplying the calculated heat exchange coefficient hl by this ratio, we obtain the heat exchange coefficient for the sand-liquid mixture.

Experimental dependencies between the parameters of the heat exchange process (for SEM140-117M, particles of feldspar of medium size 50 μm with a concentration of 1000 mg/l) are shown in Figures 2 and 3. [8, 9].

From figure 3. it can be seen: at low liquid velocities (about 0.3 m / s), the difference in engine temperature can be significant and reach 6 ° C and higher. This means that unaccounted heat exchange in models of the solid phase underestimates the temperature of the SEM.

As can be seen from Figure 3, at low speeds (0.8-0.9 m/s), the interaction of particles with the boundary layer intensifies heat exchange. The effect is ensured by the fact that a large degree of freedom of solid particles helps to improve heat exchange.

The dependence of the temperature of the SEM on the speed of the sand-liquid mixture and the average particle diameter dp is shown in Fig.4.

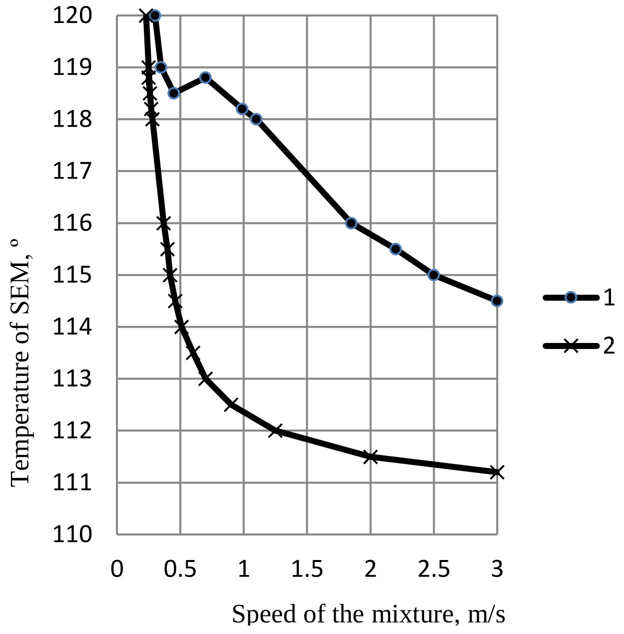

Fig. 2. The dependence of the temperature of SEM on the speed of the mixture with (1) and without (2) mechanical impurities

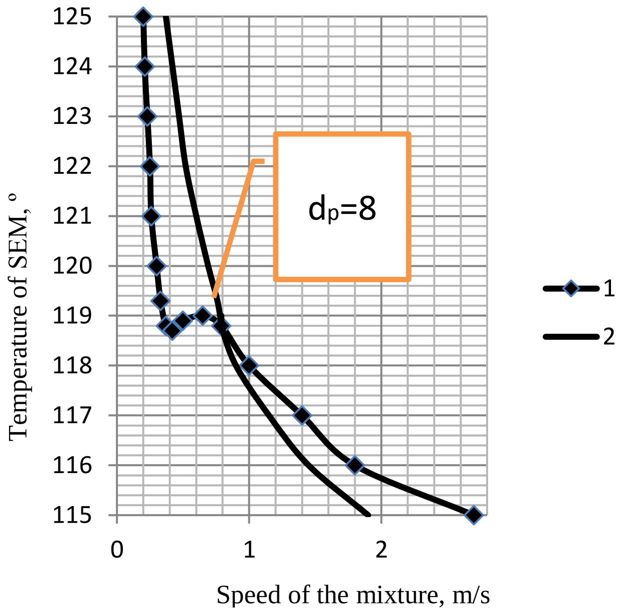

Fig. 3. The dependence of the temperature of the SEM on the mixture velocity with (1) and without (2) the interaction of particles with a viscous boundary layer

At a speed of 0.4-1.3 m/s, the layout of the installation with a housing impairs the heat exchange process, as can be seen from Figure 5.

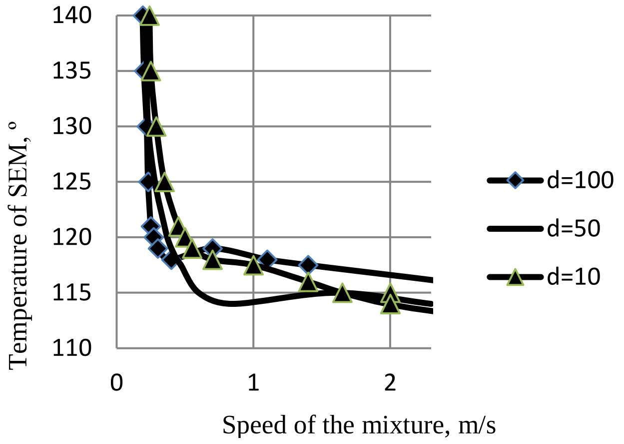

Fig. 4. The temperature dependence of the SEM on the speed of the sand-liquid mixture and the average particle diameter dp

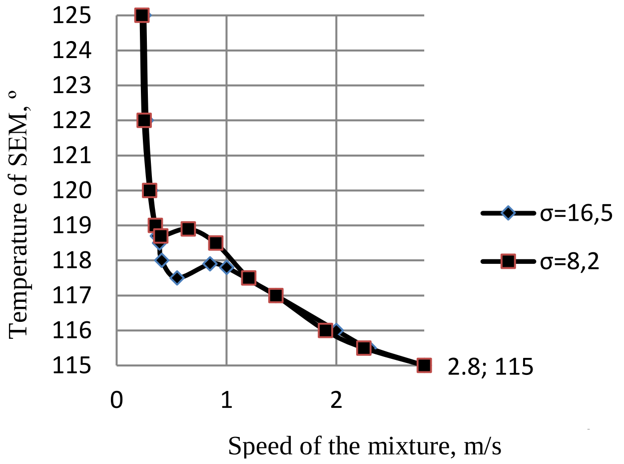

Fig. 5. Temperature dependence of the SEM from the speed of the sand-liquid mixture and the size of the annular gap between the electric motor and the production column δ

According to the proposed theory, this is due to the combined effect of the average particle diameter, the hydraulic diameter of the annular space, the concentration of particles in the mixture, which are part of the dimensionless parameter dp. At the specified flow rate and gap size of 16.5 mm, the dp parameter has a size from 2 to 6. With such values of the parameter, the particles of the solid phase actively interact with the boundary layer, reducing its thickness and thereby increasing heat exchange [2, 6].

After installing the casing, the gap value decreases, and the dp parameter becomes greater than 8 (in accordance with formula (7) at a flow velocity of 0.4-1.3 m/s.

The above reasoning makes it possible to consider the range of variation of the parameter dp within 2 - 6 as the most optimal for the effective operation of the ESP in the sand formation. Of particular importance is the preservation of the parameter dp within the specified limits for the output of wells to the mode after its development or the conduct of geological and technical measures. It is necessary to program the technological parameters of the ESP operation in such a way as to prevent the motor from overheating [10]. Periodic stops for cooling the electric motor lead to a shortage of downhole products, worsen the economic performance of the oil producing enterprise.

III. Findings

1. It has been established that when the sand-containing fluid moves upward along the annular space, the volume content of particles near the inner wall of the outer pipe (production column) is greater than that of the outer wall of the inner pipe (submersible electric motor).

2. Modeling of this movement has practical application for regulating the heat exchange process between the SEM and sand-containing fluid when conducting geological and technical measures, and especially when bringing wells to the mode:

3. The neglect of the influence of mechanical impurities in determining the heat transfer coefficient can lead to its understating more than 2 times, and the temperature of the electric motor - by 10 ° C;

4. The selection of the technological parameters of the ESP operation in such a way that the dp value falls within the interval from 2 to 6 will help to improve heat transfer and protect the electric motor from overheating;

5. At dp values> 8, the heat transfer is reduced, which can lead to overheating of the SEM;

6. Installation in the wells of filtering devices to protect pumps does not remove the problem of protecting the SEM from overheating. Some part of the sand in any case will remain in the extracted products.

It should also be noted that when mounting filters, the load on the SEM increases due to the increase in hydraulic resistance.

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