Method for leakage measurement in the recirculation path of a hermetic pump

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Abstract. The article is devoted to the measurement of leakage in the recirculation path of a hermetic pump. The field of application of hermetic pumps is described. The mathematical model used in computer simulation and the mesh conditions are given. The results of the numerical modeling and the theoretical calculation are presented. The graph of the dependence of the leakage in the recirculation path on the pump head is shown. The scalar scenes of velocities and pressures in the c path are given.
Key words: hermetic pump, leak measurement.

Introduction
Nowadays, we need machines capable of pumping large volumes of chemically active liquids in large quantities. There are many different types of chemical pumps. Its main feature is to transfer fluids containing aggressive or explosive substances. This property is especially important for such industries as oil and gas, pharmaceutical, food and cosmetic industries. Examples of studies of these units are presented in[1–5].

Fig.1. Chemical pump.

The most popular among pumping equipment is the centrifugal type of devices, and hermetic centrifugal pumps make up a significant part in the segment of chemical units (Figure 1), as a result, there are a large number of works on the development of this type of machine [6,7], which can provide complete isolation of the pumped fluid, protecting the environment from possible leaks of harmful mixtures, vapors of which can form explosive compositions with air.

A distinctive feature of a chemical centrifugal pump is impermeability, which is ensured in most cases by a magnetic coupling that requires the use of sliding bearings. Permanent fluid supply for lubrication and cooling purposes is required to maintain their performance. These conditions must be provided by recirculation paths (Fig. 2), which must be pre-calculated in order to procure the working of the pump. Otherwise, overheating in the coupling can cause the magnets to fail, thereby stopping the transmission of torque [8,9] and the bearings to lose their bearing capacity [10,11,12,13].
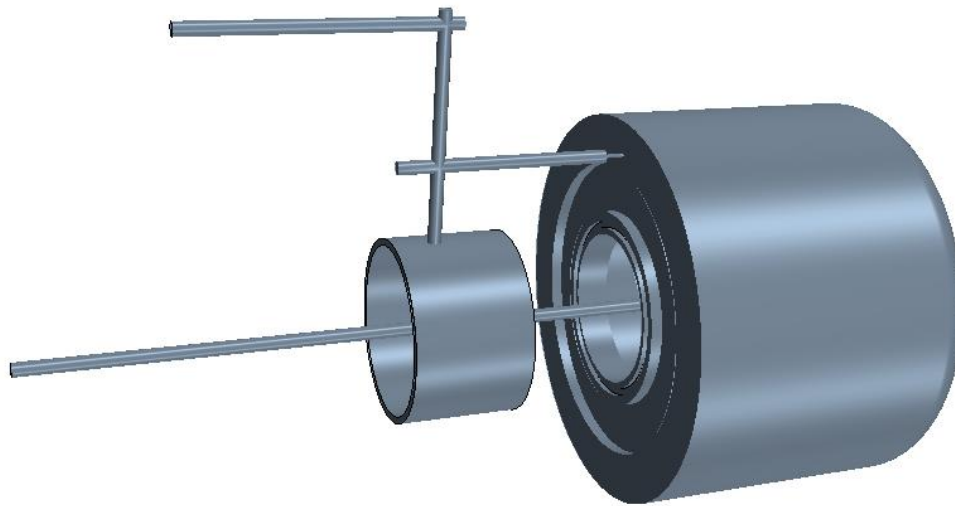

Fig. 2. Recirculation paths model.

The purpose of this work is with the help of previous studies [14] to calculate the leakage in the supply channels by means of numerical methods and theoretical calculation, also to compare the obtained results. In addition, it is necessary to reveal the dependence of the flow rate in the recirculation paths of a particular pump on its head.

1. Mathematical model and methods
Hydrodynamic simulation methods allow to determine the resistance coefficients of the channel elements without conducting tests or using inaccurate analytical dependencies. In this paper, the model of incompressible fluid [15,16] is used, and all calculations are based on discrete analogues of basic equations of hydrodynamics [17].

Mass conservation equation (continuity equation):

$$\frac{\partial \overline{u_x}}{\partial x} + \frac{\partial \overline{u_y}}{\partial y} + \frac{\partial \overline{u_z}}{\partial z} = 0,$$

where $\overline{u_i}$ — is the time averaged projections of fluid velocities on the corresponding axes;

Equation of the change in the amount of motion

$$\rho\left[\frac{\partial \overline{u_i}}{\partial t} + \overline{u_j}\frac{\partial \overline{u_i}}{\partial x_j}\right] = -\frac{\partial \overline{p}}{\partial x_i} + \frac{\partial}{\partial x_i}\left[T_{ij}^{(v)} - \rho u_i u_j\right],$$

where $\overline{u_i}\,\overline{p}$ — average speed and pressure;

$\tilde{T}_{ij}^{(v)} = 2\mu\tilde{s}_{ij}$ —viscous stress tensor for incompressible liquids;

$\tilde{s}_{ij} = \frac{1}{2}\left[\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i}\right]$ — strain rate tensor;

$\rho u_i u_j$ —Reynolds tension.

The system is closed using k-ω SST turbulence model [18,19,20]. In the wall area k-ω model is used, and in the flow kernel — k-ε model.

This model includes two equations of turbulence parameters transfer:

–the transfer equation of the turbulence kinetic energy:

$$\frac{\partial k}{\partial t} + \overline{u_j}\frac{\partial k}{\partial x_j} = P_k - \beta^* k\omega + \frac{\partial}{\partial x_i}\left[\left(v + \sigma_k v_T\right)\frac{\partial k}{\partial x_j}\right],$$

where $k = \dfrac{\left(u_x^{'2}\right) + \left(u_y^{'2}\right) + \left(u_z^{'2}\right)}{2}$ —the turbulence kinetic energy;

$u_i^{'}$ —velocity fluctuations;

P_k —a member of the turbulence energy generation;

ω —relative turbulence dissipation rate;

v_T —turbulent viscosity.

— transfer equation of relative velocity of turbulence energy dissipation:

$$\frac{\partial \omega}{\partial t} + \overline{u_j}\frac{\partial \omega}{\partial x_j} = \alpha S^2 - \beta \omega^2 + \frac{\partial}{\partial x_i}\left[\left(v + \sigma_\omega v_T\right)\frac{\partial \omega}{\partial x_j}\right] + 2\left(1 - F_j\right)\sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j}$$

The Reynolds tensions in the dynamics equations are based on the Boussinesque hypothesis:

$$\rho u_i u_j = 2\mu_T\left[\frac{1}{2}\left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i}\right) - \frac{1}{3}\frac{\partial \overline{u_k}}{\partial x_k}\delta_{ij}\right] - \frac{2}{3}\rho k\delta_{ij},$$

where δ_{ij} —Kroneker symbol.

When using the empirical closing coefficients of these equations it is possible to obtain a numerical solution of the turbulent liquid flow in the calculation area.

The local resistance coefficient is determined by the formula

$$\Delta p = \zeta\rho\frac{V^2}{2}$$

The flow part of the recirculation paths was simulated with a mesh consisting of 2.7 million cells. In the core of the flow cell have a polyhedral shape, the solid walls of the pipe - prismatic. The design mesh for the recirculation paths is shown in Figure 3.
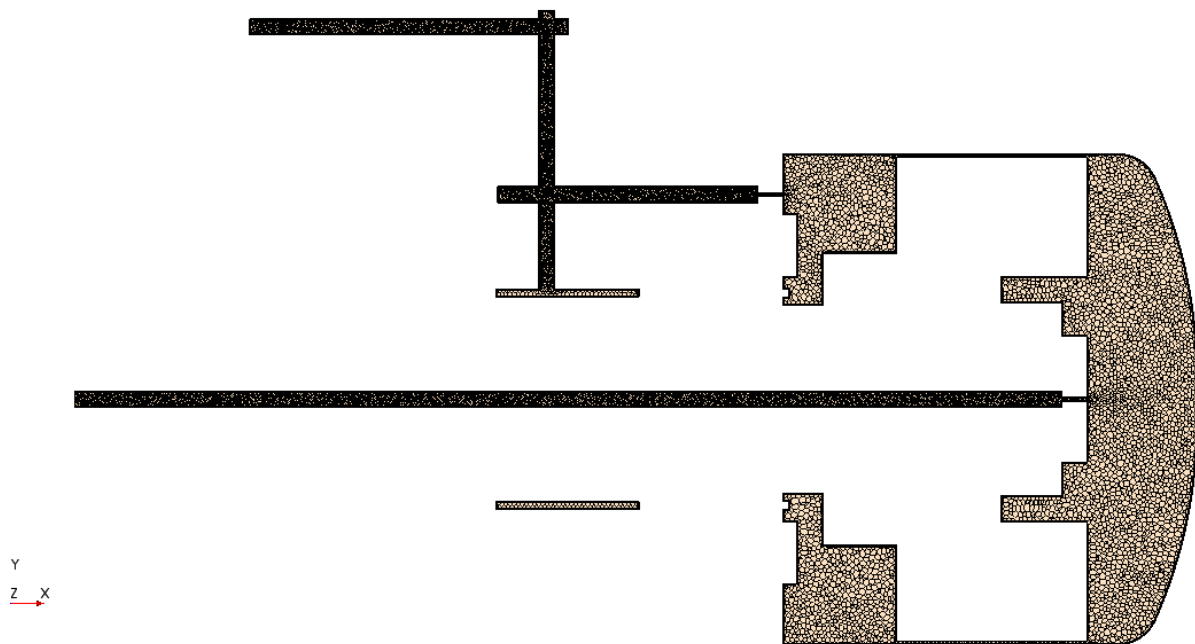
Fig.3. Mesh**.**

2. Results and analysis

Boundary conditions of calculation are outlet pressure ($P_o = 0$ Pa) and stagnation at the inlet (wheel head $H = 519341.4$ Pa). In order to determine the dependence of the flow rate in the recirculation paths on the head, a calculation was made at different pump pressures. The dependence is shown in Figure 4.
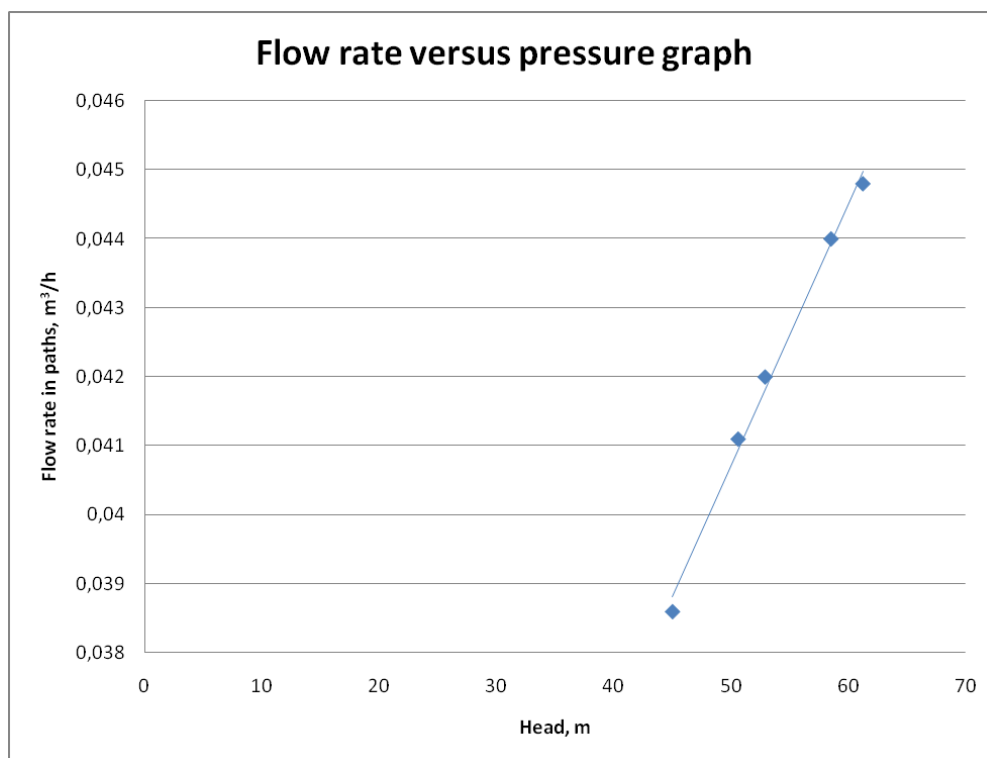

Fig. 4. Flow rate versus head graph.

The flow rate at nominal mode is Q= 0,042m^3/h.
Figures 5.6 show the scene of pressure and velocity distribution in the recirculation channels.
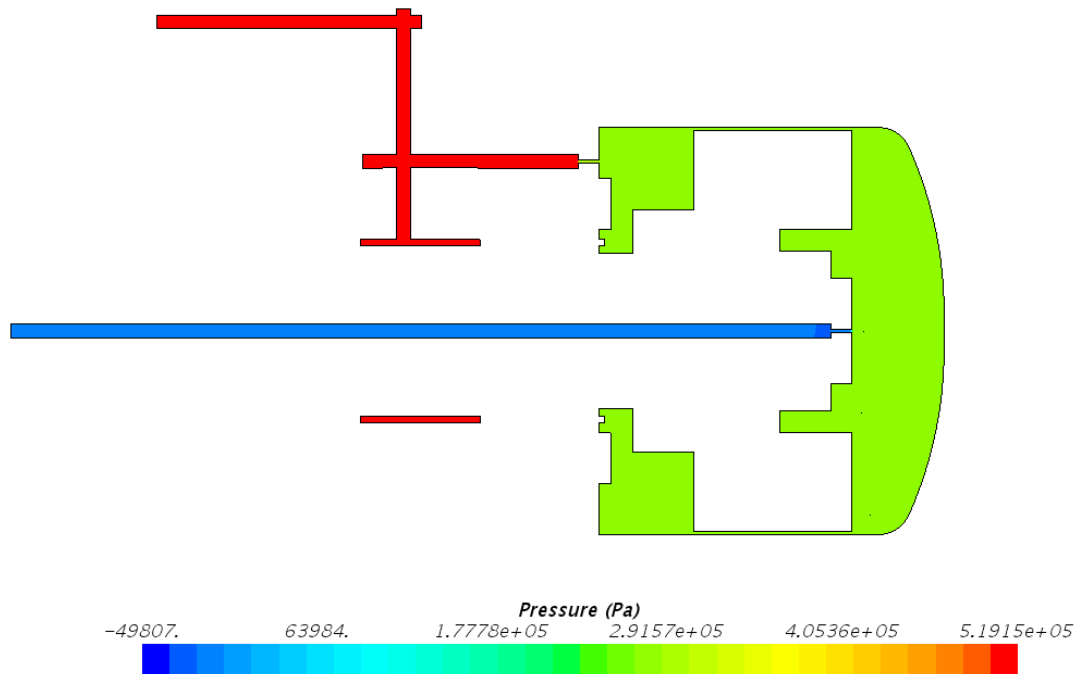

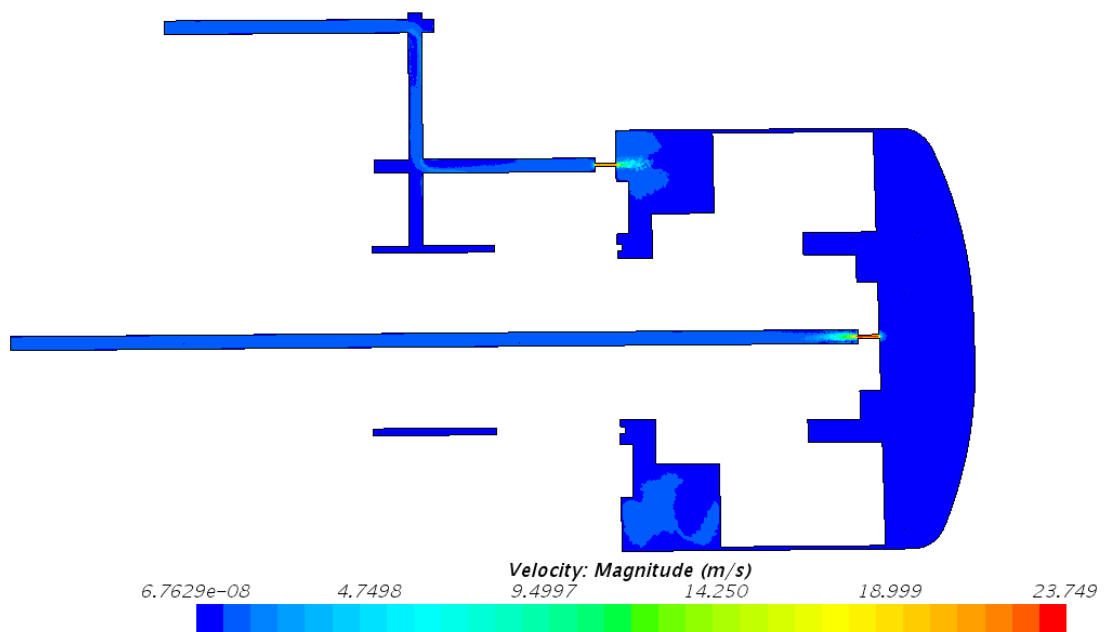**Fig.5.**Pressure distribution scene in recirculation paths.

Fig.6. Velocity distribution scene in recirculation paths.

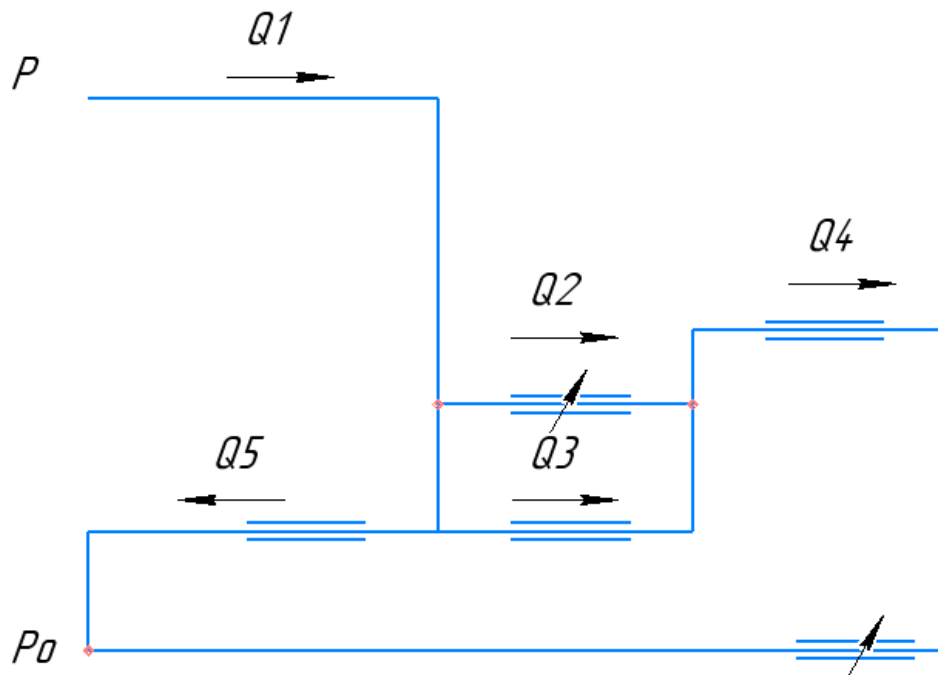Figure 7 shows the scheme of recirculation paths, which is necessary for theoretical calculation.

Fig.7. Scheme of recirculation paths

The system for calculating offlow rate.

$$
\begin{cases}
Q_1 = Q_5 + Q_4 \\
p - p_0 = k_p \cdot Q_5{}^2 \\
p_2 - p_0 = k_d \cdot Q_4{}^2 \\
p_1 - p_2 = k_m \cdot Q_4{}^2 \\
p - p_1 = k \cdot Q_4{}^2
\end{cases}
$$

where k_p —resistance of bearings, k_m — resistance of magnet coupling, k_d —resistance of throttle, k — total throttle and bearing resistance.

As a result of the theoretical calculation, the flow rate through the channels is $Q_1 = 0{,}0804$ m^3/h. From the above results it can be seen that the experimental values are 2 times less than the theoretical values. Thus, the real values of the volume efficiency will be higher than the calculated one.

3. Conclusions

According to the results of the conducted calculations, the dependence of the flow rate in the recirculation paths on the pump head was obtained, which allows to draw conclusions about its working capacity on different operating modes. A theoretical calculation was also carried out, the results values of which differ from the numerical modeling ones. This is explained by the fact that the theoretical method did not take into account the influence of flow rotation, friction of channels and changes in their area.

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