# HYDRAULIC CALCULATION OF POWER PLANT FOR MIXTURE TRANSPORT FROM THE BIG DEPTH

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**ABSTRACT**
In1the1pump1plant application it is often necessary to transport fluid from the depths that are greater than pump suction height. For that purpose it is not always possible to use mamut pumps because of solid ingredients in the fluid or low efficiencies. In that case one can use plants that combine turbo pumps and ejectors. In principle, turbo pump is placed above liquid level, while ejector is sunk into the liquid. In this paper is presented the calculation method for mentioned plant. Different configuration of turbo pumps and1ejectors are considered1in1order to define conditions for plant efficiency increase.1

**KEY WORDS:** pump, ejector, power plant, efficiency.

**INTRODUCTION**
In the pump plant application it is often necessary to transport fluid from the depths that are greater than pump suction height. For that purpose it is always possible to use different type of sinking pumps, but not always, because of solid ingredients or undissolved gases. In case of optimal regime, power plant efficiency is about 40 to 50 %. Using the sinking pumps, in the regimes different from optimal, efficiency is lower for 10 to 15 %. Because of that, it is possible to use plants that combine turbo pumps and ejectors. In general, turbo pump is placed above liquid level, while ejector is sunk into the liquid (Fig. 1). A various configurations of turbo pumps and ejectors are considered in order to define conditions for increasing the plant efficiency.

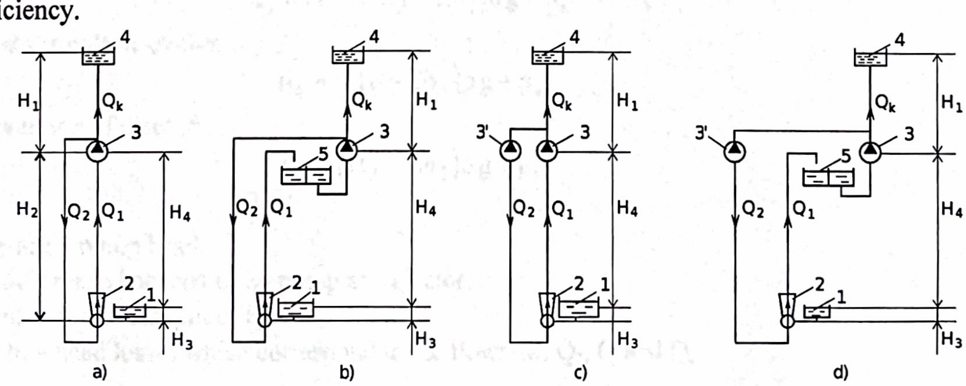


Fig. 1- Installations for fluid transport from the big depth: 1 - tank, 2 - ejector, 3 - turbo pump, 3' - auxiliary turbo pump, 4 - tank, 5 - medium tank

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Configuration shown at Fig. 1a is used for transport of the fluids which contain low solid ingredients or undissolve gases. In general, ejectors can transport fluids with solid ingredients or undissolve gases, but transport of fluid containing solid ingredients using turbo pump is not always possible, because the maximum concentration of ingredients is defined by the reliable, safety regime.

Configuration shown at Fig. 1b can be used for transport of fluids with a great deal of solid ingredients. In that case, solid ingredients transported by ejector are sedimented in the left part of medium tank. After that, the pure fluid is transported using turbo pump. Flowrate $Q_k$ and efficiency $\eta$ depend on the ratio $H_4/H_1$, where $H_1$ represents the head of turbo pump 3, and $H_4$ represents the distance between ejector and turbo pump. For increasing the plant efficiency and flowrate Qk, it is necessary to decrease ratio $H_4/H_1$, but the values $H_1$ and $H_4$ are defined by plant configuration. Because of that, by changing ratio $H_4/H_1$, it is not always possible to provide the desired values of $Q_k$ and $\eta$.

In order to increase flowrate $Q_k$ and efficiency $\eta$, we can use the power plant with two turbo pumps (Fig. 1c, 1d). This installations contain an auxiliary turbo pump 3' which increases head and transports fluid with flowrate $Q_2$. In that case, we can consider that the head of turbo pump 3 is equal to the net head of the whole network.

## 2. CALCULATION METHOD FOR FLUID TRANSPORT FROM THE BIG DEPTHS

### 2.1 POWER PLANT WITH ONE TURBO PUMP

Maximal value of efficiency of these installations is greater then the efficiency of ejectors, but lower then the efficiency of turbo pumps. A calculation methods is given below.

1. Absolute pressures in different section of ejector can be written by the parameters of installation:

- pressure in working jet

$$p_1 = (H_1 + H_2 - \Sigma h_1)\rho g + p_a$$

- pressure at the exit of ejector

$$p_4 = (H_2 - \Sigma h_2)\rho g + p_a$$

- sucking pressure of ejector

$$p_2 = (H_3 - \Sigma h_3)\rho g + p_a$$

where:

$H_1$ – whole turbo pump head,
$H_2$ – level difference between turbo pump and ejector,
$H_3$ – geometric suction height of ejector,
$\Sigma h_1$, $\Sigma h_2$, $\Sigma h_3$ – head losses which correspond to the flowrates $Q_2$, Q and $Q_k$.

2. Non-dimensional ratio of pressures $\Delta p_4/\Delta p_1$ of ejector

$$\frac{\Delta p_4}{\Delta p_2} = \frac{(H_2 - \Sigma h_2) - (H_3 - \Sigma h_3)}{(H_1 + H_2 - \Sigma h_1) - (H_3 - \Sigma h_3)}$$

Supposing that the head losses are neglected comparing to the whole head (when the pipeline has the corresponding diameter), it will be:

$$\frac{\Delta p_4}{\Delta p_2} = \frac{H_2 - H_3}{H_1 + H_2 - H_3} = \frac{1}{1 + H_1/(H_2 + H_3)}$$

The value $H_4=H_2-H_3$ is the head at the exit of an ejector. Generally, ejector can transport fluid to the axis of the turbo pump, but also up and down (Fig 2), making PODPRITISAK or NADPRITISAK at the sucker of ejector. Transport height depends on head H4 (head at the exit of the ejector).

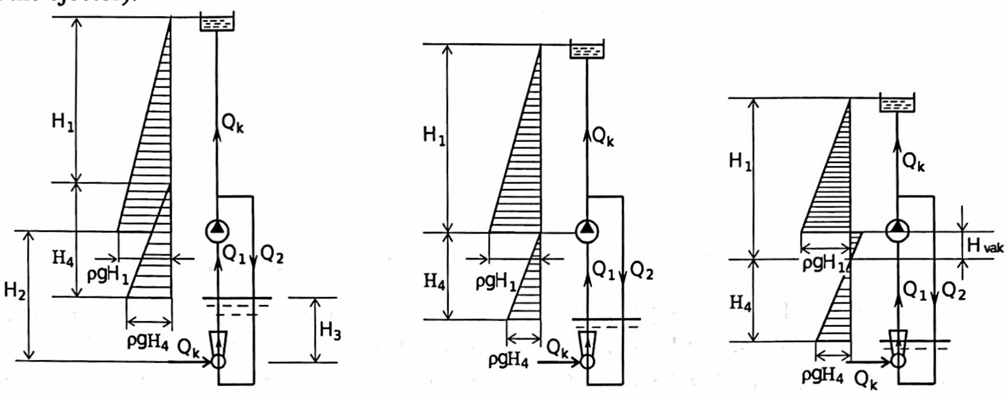


Fig 2 - Head distribution in different installation

3. From the previous expressions, follows that the pressure ratio $\Delta p_4/\Delta p_1$ and fluid ejector flow coefficient $u=Q_1/Q_2$ depend on values $u=f[H_1/(H_2-H_3)]$ or $u=f(H_1/H_4)$. The ratio $H_1/H_4$ is always known, and it is function of $\Delta p_4/\Delta p_1$. Using non-dimensional characteristic$\Delta p_4/\Delta p_1=f(u, d_3/d_1)$ we can determine fluid flow coefficient in optimal regime. Also, we can determine optimal geometric parameter $d_3/d_1$. The flowrate $Q_k$ of installation is $Q_k=u(1+u)$.

4. Power plant efficiency $\eta_i$ is the ratio of net installation power $P_k=\rho g Q_k(H_1+H_4)$ and net turbo pump power $Pp=\rho g Q_1 H_1$, i. e.

$$\eta_i=\frac{P_k}{P_p}=\frac{Q_k}{Q_1}\cdot\frac{H_1+H_4}{H_1}\cdot\eta_p=\frac{u}{u+1}\cdot\left(1+\frac{H_4}{H_1}\right)\eta_p=\eta_h\cdot\eta_p$$

where $\eta_h$ is hydraulic efficiency of installation.

5. Non-cavitation regime of ejector is provided if pressure ratio p1/p2 is determined from the equality condition of flow coefficient u and cavitation flow coefficient uk (1(. For water mixtures we can write:

$$u_k=f[(H_3+10)/H_4, H_1/H_4]$$

Using the general non-dimensional characteristics of ejectors [1], we can determine non-dimensional characteristics of installation $Q_k/Q_1$, hydraulic efficiency $\eta_h$, ratio $(H_3+10)/H_4$ which is necessary for non-cavitation work of ejector, and geometric parameter $d_3/d_1$. All these values are function of $H_4/H_1$ (Fig 3).

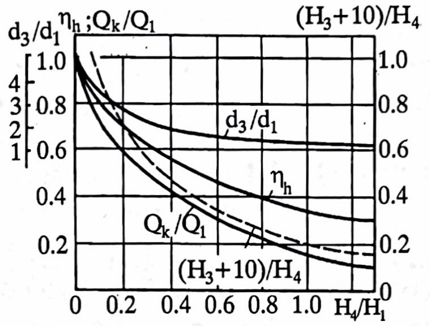


Fig. 3 - Non-dimensional characteristics of installation with one turbo pump

Analyzing the diagram, we can conclude that with the increasing ratio $H_4/H_1$, ratio $Q_k/Q_1$ decreases, as well as a hydraulic efficiency $\eta_h$, geometric parameter $d_3/d_1$, and ejector suction height, which is necessary for non-cavitation installation work. In same cases ejector can be placed beyond fluid level in tank 1. Diagram from Fig. 3 can be used for calculation of power plants shown at Fig 1a and Fig 1b, which are for the transport of fluids with a great deal of solid ingredients. In the other case, height $H_4$ is always equal to difference of the fluid level in tank 1 and tank 5.

Calculation method described above is for the optimal regime. Since the ratio $H_4/H_1$ is changeable value, because of the fluid level changing during the time, it is useful to calculate characteristics $H$-$Q_k$ for the installation with the constant value $d_3/d_1$.

The characteristics $H$-$Q_p$ of centrifugal turbo pump, where "a" represent the working point at the base working regime. From the total head $H_p$, we can determine the ratio $Q_k/Q_1$, and ratio $Q_m/Q1=1-Q_k/Q_1$, where $Q_m$ represent flowrate through ejectors jet. For determination of the ejectors jet diameter d1, we use equation

$$Q_m=\varphi_1 \cdot \frac{\pi d_1^2}{4}\sqrt{2g\Delta H_p}$$

where $\Delta H_p=H_1+H_4$ and $\varphi_1$ is jet velocity coefficient. Using this equation, we can form the ejector jet characteristics $H$-$Q_m$. Working point "a" is intersection of the lines $H$-$Q_m$ and $H_a=H_1+H_4=H_p+H_4$, and it defines jet flowrate $Q_m$. In case of configuration shown at Fig. 1a, by changing the head $H_4$, at the exit of the ejector, we can change the net head. The new value of net head is determined by the straight line $H_b$. Point "b" is the intersection of the lines $H_b$ and $H$-$Q_m$. New net flowrate is determined by the segment b-b'. By projecting b to the characteristic $H$-$Q_p$, we get the point b''', which, principally, has not to be identically to the point a. Then manometer head can increase for $H_4$', but in the practically, it is not possible. (If we decrease the flowrate, the manometer head has to be decreased)

Analyses of curves $Q_k/Q_1=f(H_4/H_1)$ and $\eta_h= f(H_4/H_1)$ shows that at the some values of $H_4/H_1$, power plant 1a and 1b are very inefficient. In order to increase an efficiency, it is possible to use installation with two turbo pumps (Fig 1c, 1d). The pump 3 gives the main head H1, while the pump 3' gives the head which is necessary for the ejector.

**2.2 POWER PLANT WITH TWO TURBO PUMPS**

Similarly to the installation with the one turbo pump, non-dimensional pressure ratio is

$$\frac{\Delta p_4}{\Delta p_1} = \frac{H_4}{H_1 + H_2 + H_4} = \frac{1}{1 + H_1 / H_4 + H_2 / H_4}$$

Necessary installation flowrate is $Q_k = uQ_2$ and at the other side $Q_k/Q_1 = u(u+1)$, so the appropriate flowrate is $Q_2/Q_1 = 1/(1+u)$

The efficiency of the installation $\eta_i$ can be defined as a ratio of net power of installation and sum of net powers of turbo pumps 3 and 3', i. e.

$$\eta_i = \frac{\rho g Q_k (H_1 + H_4)}{\rho g Q_1 H_1 / \eta_{p3} + \rho g Q_2 H_2 / \eta_{p3'}} = \frac{u(1 + H_1 / H_4)}{(1+u) / (H_1 / (H_4 \eta_{p3})) + H_2 / (H_4 \eta_{p3'})}$$

where $\Delta p_3$ and $\Delta p_4$ are the efficiency of turbo pumps 3 and 3'.

Using previous equations we can form non-dimensional hydraulics characteristic of installation

$$Q_k/Q_1 = f(H_1/H_4, H_2/H_4)$$

$$\eta_h = f(H_1/H_4, H_2/H_4)$$

and the ratio $d_3/d_1$ and $(H_3+10)/H_4$

$$d_3/d_1 = f(H_1/H_4, H_2/H_4)$$

$$(H_3+10)/H_4 = f(H_1/H_4, H_2/H_4)$$

FIG 5

Fig. 5 shows the curves $Q_k/Q_1 = f(H_1/H_4, H_2/H_4)$, where dashed line represent hydraulic efficiency of installation with two turbo pumps. It can be concluded that with increasing of $H_2$ (which is given by auxiliary pump), $Q_k/Q_1$ increases too, and with increasing of $H_4/H_1$, ratio $Q_k/Q_1$ is close to zero. It means that turbo pump head $H_1$ is too small comparing to the total (ejector and turbo pump) head.

Hydraulic efficiency $\eta_h$ decreases with the increase $H_4/H_1$ and with the increasing $H_2$ (in that case we have the increase of flowrate $Q_k$).

FIG 6

Figure 6 shows the values of optimal geometric parameter of ejector in function of $H_4/H_1$ with the different values of $H_2/H_4$. Dashed line represents the installation with the one turbo pump ($H_2=0$). By increasing $H_4/H_1$ and decreasing $H_2/H_4$, optimal geometric parameter decrease.

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