Experimental Analysis of Main Characteristics Ejectors, Comparative Analysis of Experimental Data Calculatedly Characteristics

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***Abstract* - Ejectors are used to lower the temperature of water in the district heating system at the level of system temperature 90/70°C. The basic advantages of the ejector, as a unit for mixing, the simplicity, safety and which has no moving parts. To work the ejector is necessary to have the terminal consumers significant difference in effort between supply and return water heat networks, at the expense of that is getting increased water velocity at the exit of the ejector nozzle, it is necessary to create the effect of injection (mixing). Therefore, the flow of water in the local heating system will change in direct proportion to the flow of water from the thermal network through the ejector nozzle. Serious deficiencies schemes with the absence of a ejector independent circulation of water in the local heating plant. When you cut the flow of water from the heat network in the ejector nozzle, for example, the exclusion of the thermal network fault, the interrupted water circulation in the installation of heating, which can lead to the freezing of water in service. When the account pressure drop in heating systems and 15,000 Pa usually applied ejector, and more pressure is used centrifugal pumps.**

Keywords:* *Eejector,Ccalculated, Experimental, Comparative,Aanalysis.

1.Preliminary note

To work ejector, Figure 1, it is necessary to have the terminal consumers significant difference in effort between supply and return water heat networks, the account that is getting increased water velocity at the exit of the ejector nozzle, it is necessary to create the effect of the injection. Ejector practically realized the constant coefficient of injection (mixing). Therefore, the flow of water in the local heating system will change in direct proportion to the flow of water from the thermal network through the ejector nozzle.

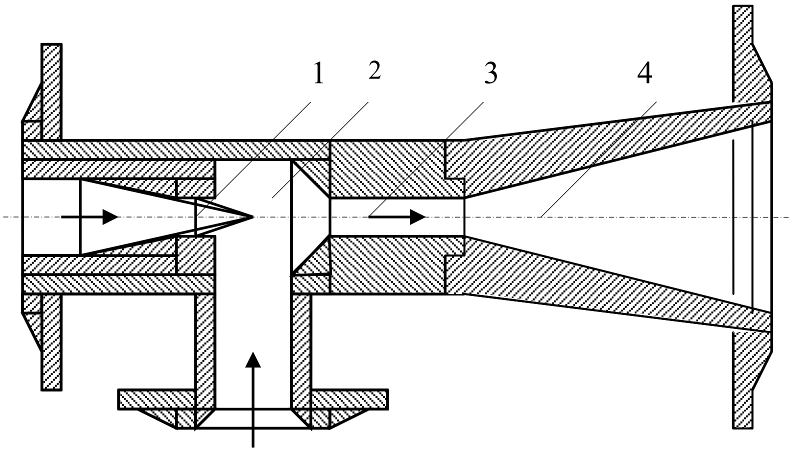


Figure 1. Cross section of the ejector (1-jets; 2-receiving chamber; 3-mixing chamber; 4-diffuser)

The original expression for the calculation of the ejector, is derived from the equation for the exchange of impulses in the mixing chamber, Figure 2, which has the following form:

$$\varphi_2\left(G_r \cdot W_{r1} + G_{in} \cdot W_{n2}\right) - \left(G_n + G_r\right) \cdot W_3 = \left(p_3 - p_{n2}\right) \cdot f_{n2} + \left(p_3 - p_{r1}\right) f_{r1} = p_3 f_3 - p_{n2} f_{n2} - p_{r1} f_{r1} \dots \quad (1)$$

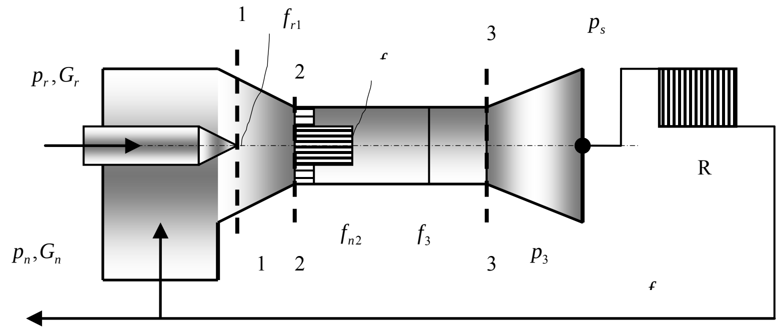


Figure 2. Model for the calculation of the ejector

From the equation of continuity of the velocity are obtained in the individual cross sections in the form of:

$$W_{r1} = G_r \cdot v_{r1} / f_{r1} \quad (2)$$

$$W_{n2} = G_n \cdot v_n / f_{n2} \quad (3)$$

$$W_3 = \left(G_r + G_n\right) v_s / f_3 \quad (4)$$

Applying the equation of energy, according to:

$$p_3 = p_s - \frac{W_3^2 \varphi_3^2}{2 v_s} \quad (5) \qquad p_{n2} = p_n - \frac{W_n^2}{2 v_s \cdot \varphi_4^2} \quad (6)$$

$$p_{r1} = p_r - \frac{W_{r1}^2}{2 v_s \cdot \varphi_1^2} \quad (7)$$

Impeachment of expression (2) to (7) in equation (1) we have the following:

$$\begin{aligned}
&\varphi_2\left(\frac{G_r^2 v_r}{f_{r1}} + \frac{G_n^2 v_n}{f_{n2}}\right) - \frac{\left(G_r + G_n\right)}{f_3} v_s = \left(p_s - \frac{W_3^2 \varphi_3^2}{2 v_s}\right) f_3 - \left(p_n - \frac{W_{n2}}{2 v_n \varphi_4^2}\right) f_{n2} - \left(p_r - \frac{W_{r1}}{2 v_r \varphi_1^2}\right) f_{r1} = \\
&= \left[p_s - \frac{\left(G_r + G_n\right)^2 \varphi_3^2 v_s}{2 v_s f_3^2}\right] f_3 - \left(p_n - \frac{G_n^2 v_n^2}{2 f_{n2}^2 v_n \varphi_4^2}\right) f_{n2} - \left(p_r - \frac{G_r^2 v_r^2}{2 f_{r1}^2 v_r \varphi_1^2}\right) f_{r1}
\end{aligned} \quad (8)$$

further rearranging we have:

$$\varphi_2\left(\frac{G_r^2 v_r}{f_{r1}} + \frac{G_n^2 v_n}{f_{n2}}\right) - \frac{\left(G_r + G_n\right)}{f_3} v_s = p_s f_3 - p_n f_{n2} - p_r f_{r1} - \frac{\left(G_n + G_r\right)}{2 f_3} \varphi_3^2 + \frac{G_n^2 v_n}{2 f_{n2} \varphi_4^2} + \frac{G_r^2 v_r}{2 f_{r1} \varphi_1^2} \quad (9)$$

or in the form:

$$\left(p_s - p_n\right) f_{n2} + \left(p_s - p_r\right) f_{r1} = \varphi_2 \frac{G_r^2 v_r}{f_{r1}} + \varphi_2 \frac{G_n^2 v_n}{f_{n2}} - \frac{\left(G_r - G_n\right)^2 v_s}{f_3} + \frac{\left(G_r + G_n\right)}{2 f_3} \varphi_3^2 - \frac{G_n^2 v_n}{2 f_{n2} \varphi_4^2} - \frac{G_r^2}{2 f_{r1} \varphi_1^2} \quad (10)$$

With respect to:

$$\begin{aligned}
&\left(p_s - p_n\right) f_{n2} - \left(p_r - p_s\right) f_{r1} = \left(p_s - p_n\right) f_{n2} - \left(p_r - p_n - p_s\right) f_{r1} = \\
&= \left(p_s - p_n\right) f_{n2} + \left(p_s - p_n\right) f_{r1} - \left(p_r - p_n\right) f_{r1} = \left(p_s - p_n\right) f_3 - \left(p_r - p_n\right) f_{r1} = \Delta p_s f_3 - \Delta p_r f_{r1}
\end{aligned} \quad (11)$$

where:

$$\Delta p_s f_3 - \Delta p_r f_{r1} = \frac{G_r^2 v_r}{f_{r1}}\left(\varphi_2 - \frac{1}{2\varphi_1^2}\right) + \frac{G_n^2 v_n}{f_{n2}}\left(\varphi_2 - \frac{1}{2\varphi_4^2}\right) - \frac{(G_N + G_r)^2 v_s}{f_3}\left(1 - \frac{\varphi_3^2}{2}\right) \tag{12}$$

Dividing equation (12) with the expression $G_r^2 = 2\varphi_1^2 f_{r1} \frac{\Delta p_r}{v_r}$ is obtained:

$$\frac{\Delta p_s f_3 v_r}{2\Delta p_r f_{r1}\varphi_1^2} - \frac{\Delta p_r f_{r1} v_r}{2\Delta p f_{r1}\varphi_1^2} = \frac{v_r}{f_{r1}}\left(\varphi_2 - \frac{1}{2\varphi_1^2}\right) + \frac{U^2 v_n}{f_{n2}}\left(\varphi_2 - \frac{1}{2\varphi_4^2}\right) - \frac{(1+U)^2}{f_3}\left(1 - \frac{\varphi_3^2}{2}\right) \tag{13}$$

or in the form:

$$\frac{\Delta p_s}{\Delta p_r}\frac{f_3}{2 f_{r1}\varphi_1^2} = \frac{v_r}{2 f_{r1}\varphi_1^2} - \frac{v_r}{2 f_{r1}\varphi_1^2} + \frac{v_r \varphi_2}{f_{r1}} + \frac{U^2 v_n}{f_{n2}}\left(\varphi_2 - \frac{1}{2\varphi_4^2}\right) - \frac{(1+U)^2}{f_3}\left(1 - \frac{\varphi_3^2}{2}\right) v_s \tag{14}$$

The final form of equation (14) is:

$$\frac{\Delta p_s}{\Delta p_r} = \varphi_1^2 \frac{f_{r1}}{f_3}\left[2\varphi_2 + \left(2\varphi_2 - \frac{1}{\varphi_4^2}\right)\frac{v_n}{v_r}\frac{f_{r1}}{f_{n2}} U^2 - \left(2 - \varphi_3^2\right)\frac{v_s}{v_r}\frac{f_{r1}}{f_3}(1+U)^2\right] \tag{15}$$

From equation (15) it can be seen that for a given mixing coefficient (U) pressure drop is proportional to the pressure drop ejector racial fluid. Similarly, we can conclude that the relation $\Delta p_s/\Delta p_r$ depends on the relation flow ejector section f_3/f_{r1}, the coefficient of velocity specific parts ejector ($\varphi_1, \varphi_2, \varphi_3, \varphi_4$), injection coefficient (U) and does not depend on the absolute size of the available pressure of the working fluid Δp_r.

When compared to the cross section $f_3/f_{r1} > 4$, which is commonly used in practice, equation (15) gives high accuracy in all its oblstima priemne, from

$$(\Delta p_s/\Delta p_r)_{U=0} \text{ do } \Delta p_s/\Delta p_r = 0 \tag{16}$$

In practice, applied and highly demanding ejectors, where the ratio of surface $f_3/f_{r1} < 4$. In calculating such ejectors, equation (15) gives a higher pressure drop values in $\Delta p_s/\Delta p_r$ major areas koeficijentaa injection (U). Calculation of the characteristics of such ejector is done via another equation that takes into account the change in the fluid flow section at the entrance part of the mixing chamber $f_{r2} < f_{r1}$, which allows the reduction of static pressure at the inlet part of the mixing chamber, the $p_r < p_n$. This equation has the form:

$$\frac{\Delta p_s}{\Delta p_r} = \varphi_1^2 \frac{f_{r1}}{f_3}\left[2\varphi_2 \frac{f_{r1}}{f_{r2}} + 2\varphi_2 \frac{v_n}{v_r}\frac{f_{r1}}{f_{n2}} U^2 - \left(2 - \varphi_1^2\right)\frac{v_s}{v_r}\frac{f_{r1}}{f_3}(1+U)^2 - \frac{\Delta p_k}{\Delta p_r}\right] \tag{17}$$

Therefore, we have:

$$\frac{\Delta p_k}{\Delta p_r} = \frac{\frac{\varphi_1^2}{\varphi_4^2}\frac{v_n}{v_r}U^2}{\frac{f_3}{f_{r1}} - \frac{1}{\sqrt{1 + \frac{\Delta p_k}{\Delta p_r}}}} \tag{18}$$

$$\frac{f_{r1}}{f_{r2}} = \sqrt{1 + \frac{\Delta p_n}{\Delta p_r}} \tag{19}$$

$$\frac{f_{r1}}{f_{n2}} = \frac{f_{r1}}{f_3 - f_{n2}} = \frac{1}{\frac{f_3}{f_{r1}} - \frac{f_{r2}}{f_{r1}}} \tag{20}$$

For injection coefficient U = 0, ejector develops a maximum ratio $\Delta p_s / \Delta p_r$, which is determined by the equation:

$$\left(\frac{\Delta p_s}{\Delta p_r}\right)_{\max} = \varphi_1^2 \frac{f_{r1}}{f_3}\left[2\varphi_2 - \left(2-\varphi_3^2\right)\frac{f_{r1}}{f_3}\right] \qquad (21)$$

Characteristic equation without ejector diffuser has the following form:

$$\frac{\Delta p_3}{\Delta p_r} = \varphi_1^2 \frac{f_{r1}}{f_3}\left[2\varphi_2 - \left(2\varphi_2 - \frac{1}{\varphi_4^2}\right)\frac{v_n}{v_r}\frac{f_{r1}}{f_{n2}}U^2 - 2\frac{v_s}{v_r}\frac{f_{r1}}{f_3}(1+U)^2\right] \qquad (22)$$

For equal specific volume, equation (22) takes the form:

$$\frac{\Delta p_3}{\Delta p_r} = \varphi_1^2 \frac{f_{r1}}{f_3}\left[2\varphi_2 - \left(2\varphi_2 - \frac{1}{\varphi_4^2}\right)\frac{f_{r1}}{f_{n2}}U^2 - 2\frac{f_{r1}}{f_3}(1+U)^2\right] \qquad (23)$$

2. Experimental analysis

Experimental characteristics of ejectors were tested in the laboratory of Mechanical Engineering, University of Pristina, in which is fitted to the experimental device is shown in Figure3.

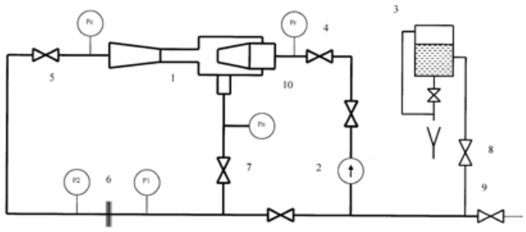


Figure 3. Experimental set ejector (1-ejector, 2- circulator pump, 3-expansion court, 4-valve in front of the ejector nozzle, 5-valve imitation of resistance heating system, 6-measuring grinders, 7-valve suction ejector, 8-valve drain water from the expansion vessel, 9-valve system for supplying water from the water mains, 10-jet ejector)

For different values otvranja valve 4 pressure values were read p_r, p_n, p_s, p_1, p_2. Consumption of water working G_r is determined from the pressure drop at the nozzle ejectors, starting from the equation:

$$f_{r1} = \frac{G_r}{\varphi_1}\sqrt{\frac{v_r}{2\Delta p_r}} \qquad (24)$$

that is:

$$G_r = 2{,}8 \cdot 10^{-4}\sqrt{\Delta p_r} \qquad (25)$$

Where is the pressure difference $\Delta p_r = p_r - p_n$ is expressed in Pa.

Consumption of mixed water is determined from the pressure drop on the viewing grinders:

$$G_s = 1{,}25 \cdot 10^{-3}\sqrt{\Delta p_s} \qquad (26)$$

Where $\Delta p_s = p_2 - p_1$ is the pressure drop on the viewing grinders expressed in Pa, while the consumption of G_s obtained in the kg/s

The amount of injected water:

$$G_n = G_s - G_r \qquad (27)$$

Upon determination of G_n and G_r, determine the coefficient of $u = G_n / G_r$ shots for a given mode. On the experimental installation, Figure 3, are built ejectors following characteristics:

Knowing the ratio of areas f_3 / f_{r1} and u coefficients injkecije get a point in the coordinate system. Experimental test results are shown in Figure 4 . The results show that the change of pressure in front of the ejector nozzle p_r, mean changes in pressure difference $p_r - p_n$, the gradual opening of the valve 4, the injection coefficient and pressure ratio is around $\Delta p_s / \Delta p_r$ constant size, while the size of a variable in a system of labor occurs consumption of water and injected water, Figure 4, A regime.

Table T1. Characteristics ejector

Ordinal number	Diameter,mm		relationship
	Chambers mixing	Nozzle	f_1/f_3
1	10	3	0,0900
2	25	5,20	0,0432
3	30	5,10	0,0289
4	35	6,10	0,0305
5	47	9,50	0,0041

Knowing the ratio of areas f_3/f_{r1} and get the point of injection coefficient in the coordinate system. Experimental test results are shown in Figure 4. The results show that the change of pressure in front of the ejector nozzle, means changing the pressure difference, the gradual opening of the valve 4, the injection coefficient and pressure ratio is

At the same pilot plant tests were performed, the characteristics of the ejector with the change in resistance of the meat system.

When the gradual closing of the valve 5 increased resistance heating systems and dobeijene the different values of the injection and relation of pressure drop, Figure 4/1, the regime B. During testing valves 4 and 7 , were completely open.

As can be seen from the test results, there is a limit to increase the resistance of the meat of the system, since the injection coefficient becomes negative, which means it does not perform ejector suction povrtanog water from the water, but on the contrary, a certain amount of water from the water flows to the timing return line. In this case the form hidroulička two rounds: one is the movement of water from the water through a valve timing 7 in return, and the second is the movement of water from

approximately constant values, while a variable size in system performance occurs consumption of water and injected water, table T1 mode A .

Results of experimental tests, the results confirm ispitivanjog injection coefficient, equation (28) and (29):

$$U = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \qquad (28)$$

Where:

$$a = \frac{b}{2} - \left(2\varphi_2 - \frac{1}{\varphi_4^2}\right)\frac{f_3}{f_{n2}};$$

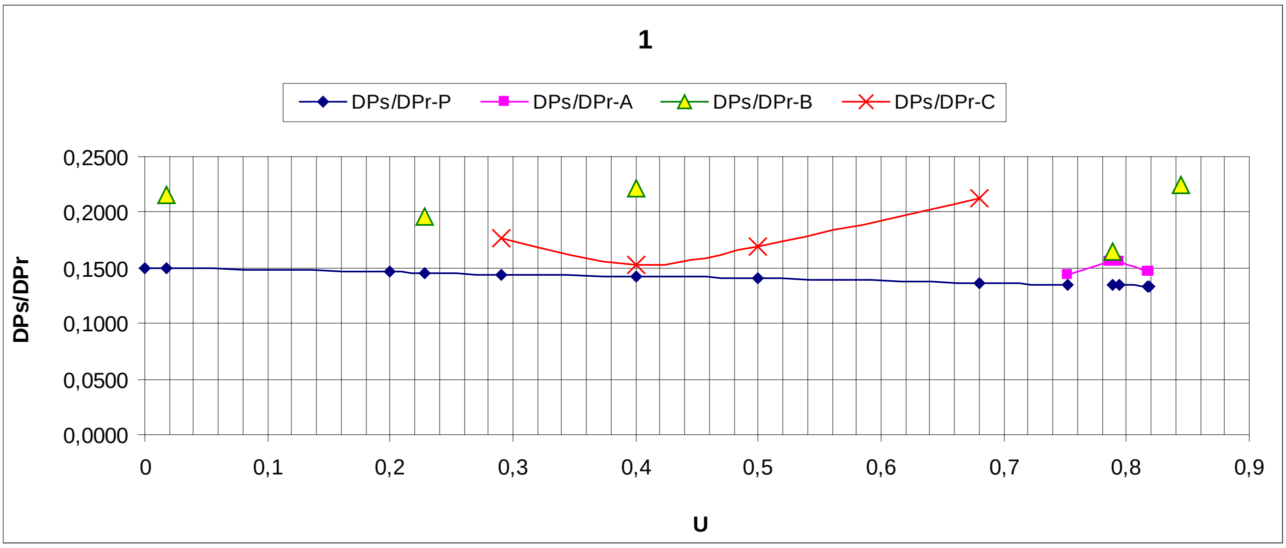
$$b = 2\left[2 - \varphi_3 + 2S_s\, f_3^{\,2} v_r\right] \qquad (29)$$

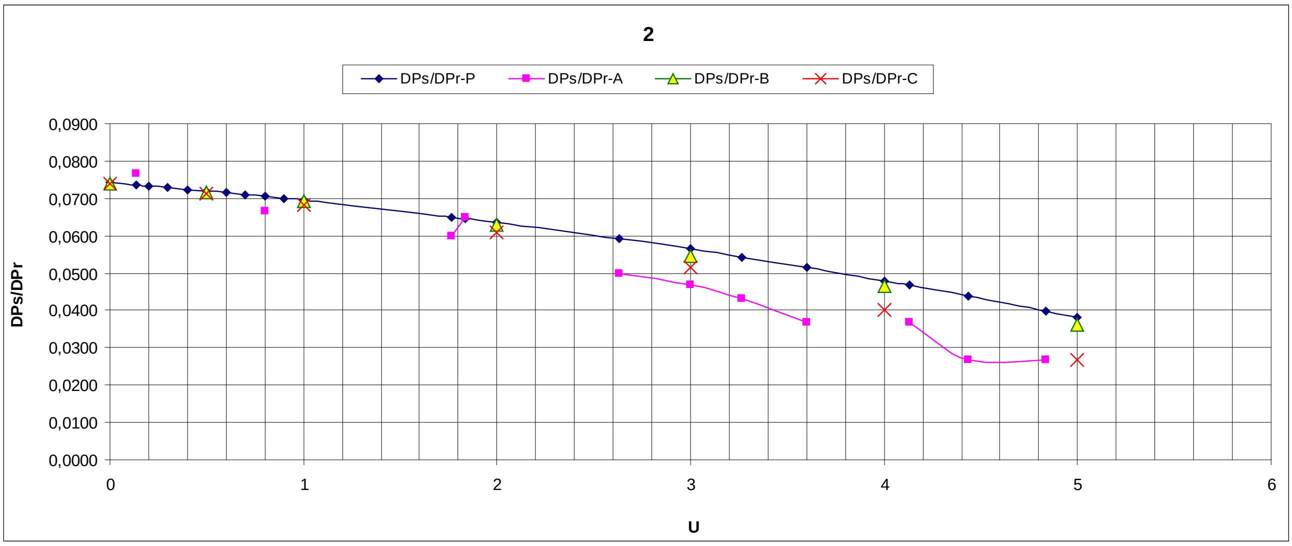
$$c = -\left(2\varphi_3 \frac{f_3}{f_{r1}} - \frac{b}{2}\right)$$

the water through a valve timing 5 in return. Further increase resistance system remains one hidroulički round water valves through seventh In this case, through the ejector is not flowing water, which means that the injection coefficient takes a minimum value of the $U = -1$.

Next examine characteristics of the ejector was carried out at total otvranju valve 4 and 5 Changes in the system of the system is achieved stepwise functional closure valve 7 at the entrance chamber for mixing. Test results are shown in Figure 4/1, C regime and show that in this regime the injection coefficient decreases.

Results tests in Figure 4 show that the actual characteristics of the ejector behind budgetary performance. It is a sign that the proposed speed ratios of some parts of the ejector, which were applied for the calculation, are higher.

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DPs/DPr-A
DPs/DPr-B
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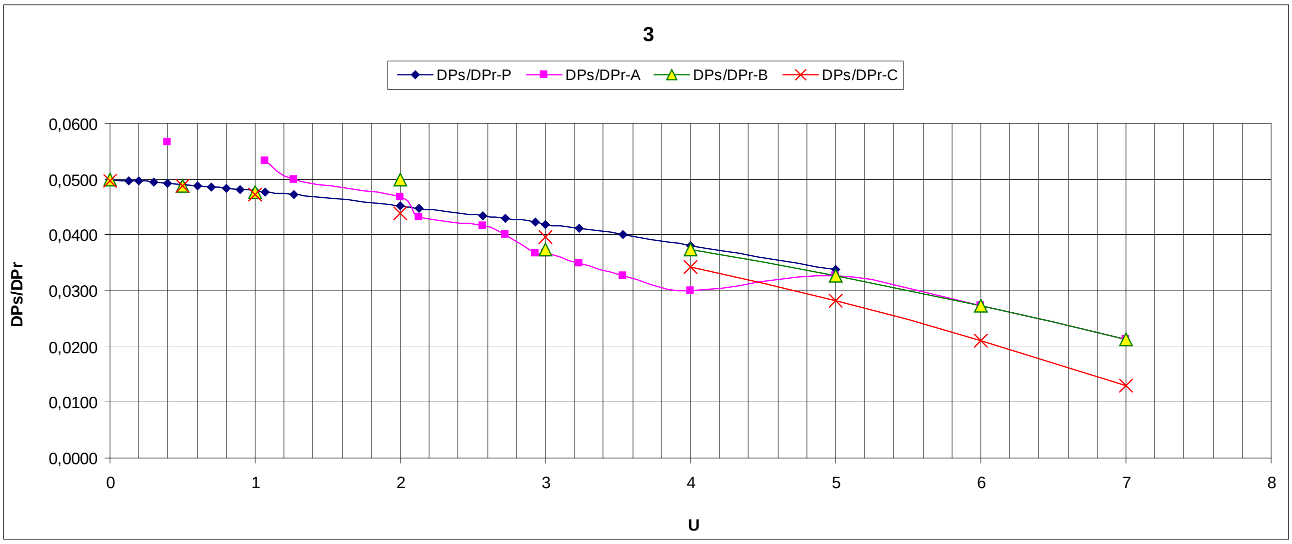
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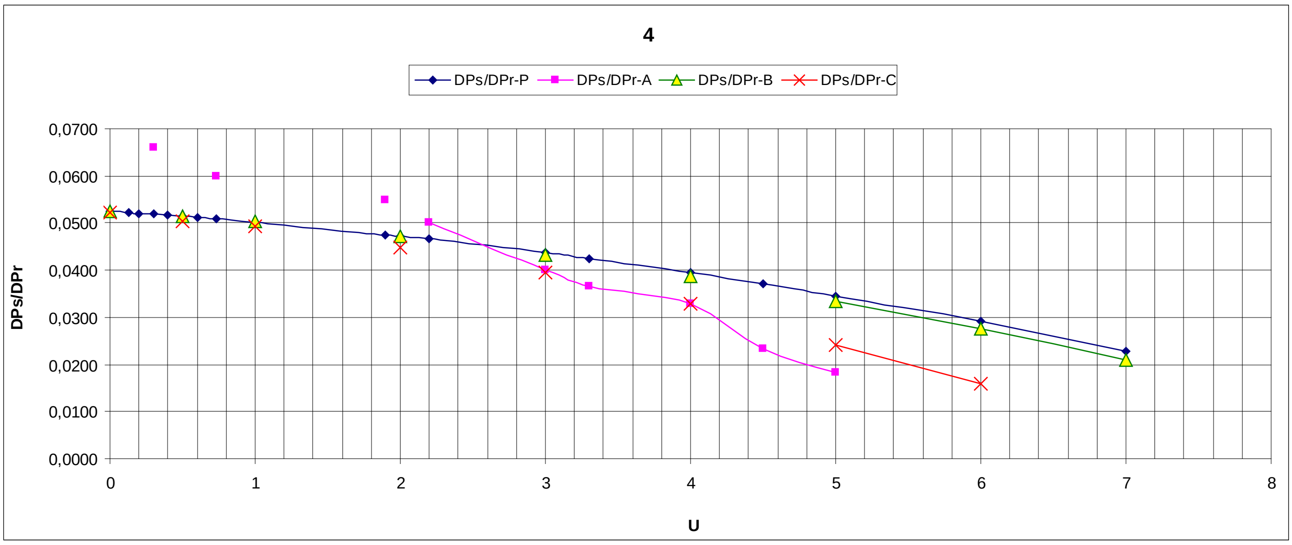
4
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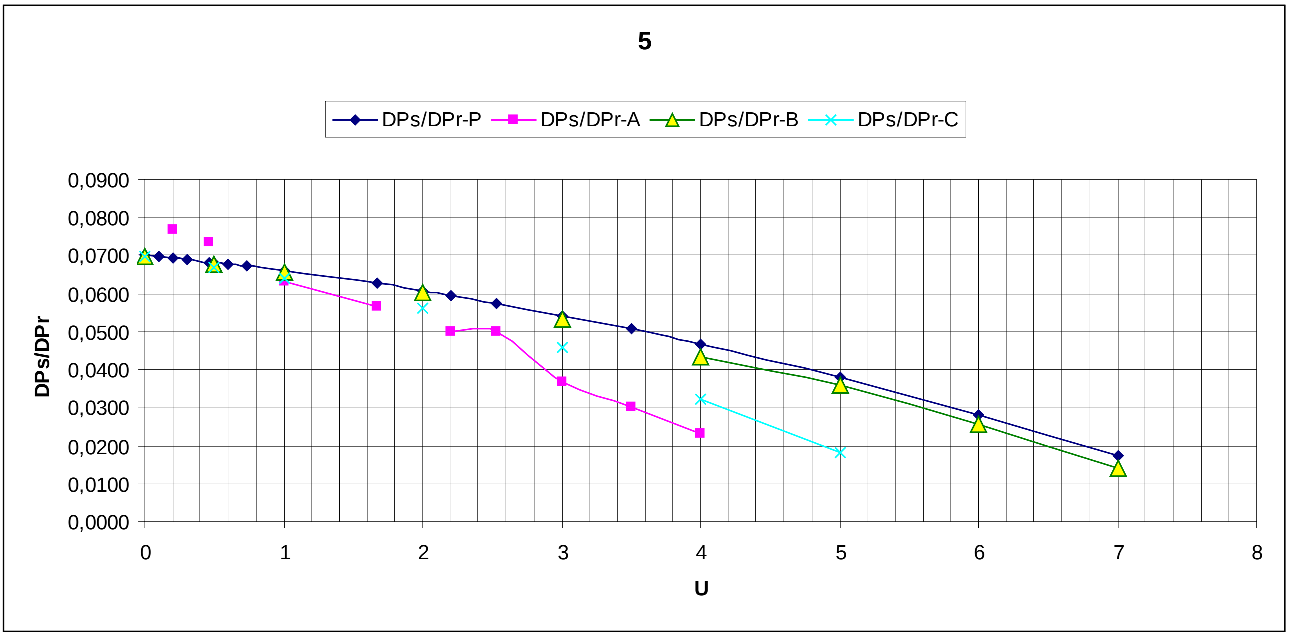

Figure 4. Calculation and experimental characteristics of ejectors in various modes (1-$d_1/d_3 = 3/10$; 2-$d_1/d_3 = 25/5.2$;3-$d_1/d_3 = 30/5.1$;4-$d_1/d_3 = 35/6.1$;5 $d_1/d_3 = 9.5/47$)
DPs/DPr-P- computational characteristics of the ejector, according to equation (15);
DPs/DPr-A- regime A;DPs/DPr-B- regim B;DPs/DPr-C- regime C;

3. Conclusion

As can be seen from the test results, there is a limit to increase the resistance of the meat of the system, since the injection coefficient becomes negative, which means it does not perform ejector suction povrtanog water from the water, but on the contrary, a certain amount of water from the water flows to the timing return line.

Results tests in Figure 4 show that the actual characteristics of the ejector behind budgetary performance. It is a sign that the proposed speed ratios of some parts of the ejector, which were applied for the calculation, are higher.

On this basis we conclude:

1. The results obtained on the ejector shown that for ordinary working conditions actually mixing ratio gets lower than the theoretical, which is calculated.This is explained by the existence of structural defects in the diffuser and the entrance part of the mixing chamber, and also the low quality production.
2. Pri budget ejector shown structures, should be taken to lower the value of the coefficient of velocity diffuser and inlet mixing chamber works.
3. To increase the effectiveness of the ejector it is necessary to perform structural refinement and increasing the quality of production parts ejectors.
4. Comparative analysis of the obtained optimal feature size $\Delta P_t/\Delta P_r = f_1(U)$ and $\eta = f_2(U)$ with the data examined, we defined speed ejector odds for over $\varphi_1, \varphi_2, \varphi_3, \varphi_4$ ejktora types and for different relations f_1/f_3. In this way, the theoretical equation for the characteristic ejectors we approached the factual situation.

4. Marks

d_1, d_3 -diameter nozzle and mixing chamber, m

p_{r1}, p_{n2}, p_3 -working pressure of the water in front of the nozzle, and the water that is injected into the cross section (2-2) and mixed water in section (3-3), Pa;

G_r, G_n -amount of working in front of the water jets and the water is injected into the input chamber, $kg/\sec$;

W_{r1}, W_{r2}, W_3 - operating speed of water, water that is injected into the section (2-2) and speed of water mixed in the intersection (3-3), $m/\sec$;

f_{r1}, f_3 -sectional area of the nozzle exit and the intersection of the cylindrical mixing chamber, m^2;

$f_{n2} = f_3 - f_{r1}$ - Sectional area of the injected flow in the inlet section of the cylindrical part of the chamber dilution m^2;

$\varphi_1, \varphi_2, \varphi_3, \varphi_4$ -coefficient of velocity jets, cylindrical mixing chamber, diffuser, parts of input mixing chamber;

v_r, v_n, v_s -Specified working volume of water, the water is injected into the inlet chamber and the water at the exit of the draft tube, m^3/kg;

$\Delta p_s = p_s - p_n$ -pressure difference created by the ejector, Pa;

$\Delta p_r = p_r - p_n$ -available duct pressure drop through the proper operating pressure, Pa;

$\Delta p_k = p_n - p_2$ -drop in static pressure at the inlet section of the chamber dilution, Pa;

$p_2 = p_{n2} - p_{r2}$ -static pressure at the inlet part of the mixing chamber Pa;

p_3 -pressure at the outlet section of the mixing chamber, Pa;

$\Delta p_3 = p_3 - p_n$ -drop in pressure at the outlet section of the mixing chamber, Pa;

U -injection coefficient

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