Specifics of using an ejector-mixer with a tangential reagent inlet

B Ksenofontov¹, Ya Vasilieva¹ and S Kapitonova¹

¹Department of Ecology and Industrial Safety, Bauman Moscow State Technical University, 5/1, 2ya Baumanskaya str., Moscow, 105005, Russia

ksenofontov@bmstu.ru

Abstract. The paper shows that mixing of water with a reagent can be successfully carried out using ejectors. The main design features of the ejector-mixer have been studied. Determined parameters of the ejector operation and features of dosing reagent, to ensure the optimal mixing process. At the same time empirical dependencies of reagent solution suction into the treated water are established. All dependencies have a linear nature. The obtained dependencies can be used in the practice of reagent water treatment.

The protection of the aquatic environment in our country has an important economic, environmental and social significance. The need to prevent pollution of water bodies has led to stricter requirements for the quality of wastewater treatment [1-2]. This in turn is reflected in more intensive use of compact high-efficiency apparatuses. Ejectors that are easy to manufacture, compact and do not require significant financial investments have become increasingly common in various technological processes [3].

The use of reagent treatment of water is one of the most common ways of intensifying its purification [4-5]. An important role here is not only the selection of the dose of the reagent, but also the process of mixing it with water [6-7]. The coagulation process itself is quite fast and in this regard, it is important to distribute the reagent in the water as evenly as possible. The intensity of the mixing process is characterized by the value of velocity gradient G (1/sec), as well as Camp criterion (1):

\[ C_a = G \cdot \tau \]  

where \( \tau \) denotes mixing time, in seconds.

Velocity gradient may be calculated using the following formula (2):

\[ G = \frac{W}{\sqrt{\mu}} \]  

where \( W \) – ratio of power lost in the mixing process to the volume of water mixed; \( \mu \) – dynamic viscosity.

Mixing time may be calculated using the following formula (3):

\[ T = \frac{V}{Q} \]  

where \( Q \) – discharge water flow, \( m^3/s \); \( V \) – effective volume of the mixing chamber, \( m^3 \).
The optimality condition for the mixing is formula (4):

\[ T = \tau \]  

(4)

Optimal mixing depends on the implementation of the conditions specified above. Rapid mixing of reagents with water, as a rule, increases the efficiency of their use. However, the use of devices with agitators for these purposes, as the most effective technical means, leads in some cases to the destruction of the resulting aggregates, which requires in this regard, strict compliance with the time interval of mixing. The most simple in terms of hardware and at the same time effective device is an ejector [8]. In this case, the ejector, functioning as a jet pump, allows dosing and mixing the reagent with waste water.

To study the mixing process of reagent and wastewater in the ejector chamber, we chose an experimental model of the ejector shown in figure 1.

![Ejector diagram](image)

**Figure 1.** Design features of the ejector

1 - Ejector cap (plastic), 2 - Rubber gasket, 3 - Curved metal partition for twisting the flow, 1 mm thick, 4 - Body of the ejector (plastic)

Various models and software products are used to study the operation modes of ejectors [9-16]. In this problem, the model was designed and investigated in the software package ANSYS (hereinafter referred to as the Program) with setting various input parameters of model operation.

A series of experiments was based on using a single-phase model, i.e., the program performed the calculation with the same fluid supply in both spigots. Heat transfer functions (energy) were not considered within the framework of the experiment. Turbulence was taken into account.

Calculation showed fast and stable reaching stationary mode of operation, the time was 60 sec.

The main parameter to study the effectiveness of using ejectors as a mixer to feed the reagent solution into the flow of treated wastewater are velocity indicators and its variation.
Figures 2-7 shows isosurfaces of liquid flow velocities, which provide a visual representation of what velocity indicators prevail in some areas inside the ejector chamber.

**Figure 2.** Isosurface $V = 12$ m/s.

**Figure 3.** Isosurface $V = 10$ m/s.

**Figure 4.** Isosurface $V = 8$ m/s.

**Figure 5.** Isosurface $V = 6$ m/s.

**Figure 6.** Isosurface $V = 4$ m/s.

**Figure 7.** Isosurface $V = 2$ m/s.

The velocity distribution contours (velocity magnitudes) at all sections of the mixing chamber of the ejector in the corresponding planes are shown in Figures 8-9.
According to the data presented in the figures, the most intense change in velocity occurs in the section of the input of the second liquid flow (reagent). In Figure 10 graphs of velocity distribution in this section of the mixing chamber with length of 3 cm are shown.

The abscissa axis is the position of the ejector section point in the Z0Y plane (perpendicular to the section shown in the figures) from the beginning of the mixing chamber. In this case, the coordinate 0.000 corresponds to the position on the axis of motion of the main flow of mixed liquids in the ejector (ejector axis in the direction 0X).

The ordinate axis shows velocity values in m/s.

In this case, the graph corresponding to the legend XZ_053, white characterizes the distribution of velocity magnitude on the segment remote from the left edge of the model by 53 mm, which corresponds to the beginning of the chamber of direct mixing of liquids. The magnitude is given in section X0Z along the length of the ejector.

Further magnitude surveying and plotting is done in 3 mm increments from the beginning of the mixing chamber.
Figure 11 shows that the velocity distribution plot XZ_053 (red) does not give "sticking" to the ejector wall, since this is the location of the reagent input (ejector spigot).

More clearly the location of this velocity graph inside the ejector body is shown in Figure 11.

![Figure 11. Velocity magnitude graphic location in the ejector body.](image)

But the single-phase model does not give a complete picture of the processes that will occur in the mixing chamber when the reagent solution is introduced into the treated wastewater through the ejector nozzle, designed for air suction (in the case of classical application of the ejector), because the mixing fluids will have different characteristics from each other and, therefore, for calculation in ANSYS they must be presented as 2 different flows. At this stage of the research there is no need to specify the specific composition of the reagent and the exact characteristics of the applied liquid, it is enough to set a two-phase calculation model in the program.

In the second series of experiments, a two-phase calculation model was set. In this case, one of the studied parameters was the homogeneity of the medium (liquid). Homogeneity in this case is directly related to the degree of wastewater treatment, because the better the reagent (flocculant, coagulant) is distributed in the treated wastewater, the higher will be the efficiency of flotation treatment.

Volume distribution of liquids (phase mixing) is shown in Figures 12-13. From the distribution we can see that to intensify the mixing process it is necessary to either twist the flows more [17], for example, by changing the design of the metal partition at the inlet of the main flow into the ejector, or by increasing the rate of fluid flow in the reagent inlet pipe. Another alternative method of intensifying the mixing process and obtaining a more homogeneous liquid at the outlet of the ejector is to increase the length of the ejector itself.

One of the main parameters characterizing the mixing process is the velocity gradient. Table 1 shows the dependence of the velocity gradient on the initial rate of water supply.

Analysis of the data presented in Table 1 shows that the velocity gradient along the X-axis as well as along the Y- and Z-axes depends significantly on the initial water supply velocity. The ratio of the velocity gradient values along the X axis to the values along the Y and Z axes is approximately 2:1.

This shows that the turbulization of the medium does not differ sharply in these directions, which, in our opinion, should provide a fairly good mixing of reagents with the treated water.

In order to verify the proposed technical solutions, an experimental setup has been created.

Principle scheme of such unit is shown in Figure 14. Wastewater is fed into the ejector 1, where at the narrow point of rarefaction the reagent solution from the tank 2 is sucked in. In the mixing chamber of the ejector solution is mixed with waste water, after which the flow enters the settling tank 3.
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Figure 12. Volumetric phase distribution (mixing), X0Z.

Figure 13. Volumetric phase distribution (mixing), X0Y.

Table 1. Dependence between velocity gradient value and water intake velocity.

| Water intake velocity, m/s | Flow, kg/s | Velocity, m/s | Nexit., % | Gradients of velocity components, s⁻¹ |
|---------------------------|------------|---------------|-----------|--------------------------------------|
|                           | Water      | Reagent       | Residual  | Mixed max. | Mixture max. | Vₓ max | Vᵧ max | Vₜ max |
| 0,4 (7s)                  | 0,102      | 0,003         | -4,7e-06 | 0,919      | 5,829        | 1,645  | 2,76   | 12776  |
| 0,8 (14s)                 | 0,203      | 0,007         | -1,0e-05 | 2,115      | 11,634       | 3,304  | 3,16   | 24162  |
| 1,2 (21s)                 | 0,305      | 0,010         | -1,5e-05 | 3,310      | 17,452       | 4,962  | 3,29   | 36226  |
| 1,6 (28s)                 | 0,406      | 0,014         | -2,0e-05 | 4,487      | 23,273       | 6,620  | 3,35   | 48302  |
| 2,0 (35s)                 | 0,508      | 0,018         | -2,4e-05 | 5,655      | 29,094       | 8,277  | 3,37   | 60406  |
| 2,4 (42s)                 | 0,609      | 0,021         | -2,8e-05 | 6,811      | 34,920       | 9,934  | 3,39   | 72532  |

Figure 14. Scheme of the installation with ejector-dosing unit:
1 - ejector, 2 - tank with reagent solution, 3 - tank sump.

Experiments have shown that when water is fed in an amount of 1 liter through the ejector 20...50 ml of reagent solution is sucked in a time of 30 seconds.

In the course of the research an empirical relationship was established:

\[ q = k \cdot Q. \]  \hspace{1cm} (5)

where \( q \) – the amount of sucked up reagent solution; \( Q \) – the amount of water to be treated; \( k \) – factor of proportionality.
The coefficient $k$ in equation (5) has a wide enough range of values and the control of this value is achieved by changing the technical way of the solution supply $q$, for example, by controlling the valve or some other device.

The resulting dependence allows you to use it in the practice of mixing purified water with reagents.

Thus, the studies have shown that the dosing and mixing of reagents with water can be reliably carried out with the use of the ejector.

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