An ejector for mixing a reagent with discharge water

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Abstract. The paper presents a research on ejectors used to mix discharge waters with flocculant or coagulant solutions intensifying the flotational discharge water treatment. Results of modelling using ANSYS environment are provided, visualizing the processes going on in the mixing chamber of the ejector as well as estimating parameters of those processes. The velocity gradient values were estimated, which is the main parameter with regard to the mixing process, and therefore characterizing the intensity of discharge water treatment. The dependency between the value of the velocity gradient and the velocity of the water entering the ejector was analyzed. It was shown that the gradient value changes nearly proportionally to the input velocity, and this dependency holds in all directions. The ration between the X component of the gradient and its Y and Z components amounts to approximately 2:1. That means, turbulization does not significantly differ direction-wise, and the mixing conditions are favorable.

1. Introduction

Treatment of discharge water using chemicals is one of the most common methods for discharge water treatment \cite{1-22}. The process of mixing reagents (in particular, coagulants) is as important for the final as the composition of the reagents. Coagulation process runs quite fast, and therefore it is crucial to introduce the coagulants into water evenly and fast. The intensity of the mixing process is characterized by the value of velocity gradient $G$ (1/sec), as well as Camp criterion.

\[ Ca = G \cdot \tau, \quad (1) \]

where

\[ \tau \] denotes mixing time, in seconds.

Velocity gradient may be calculated using the following formula:

\[ G = \frac{W}{\sqrt{\mu}}, \quad (2) \]

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:
where
\[ Q - \text{discharge water flow}, \text{m}^3/\text{s}; \]
\[ V - \text{effective volume of the mixing chamber}, \text{m}^3. \]

The optimality condition for the mixing is:
\[ T = \frac{V}{Q}. \tag{3} \]

Optimal mixing depends on the implementation of the conditions specified above.

Fast introduction of the chemicals into discharge water increases the efficiency of the water treatment process. However, the use of devices equipped with stirring paddles, considered the most efficient technology, sometimes lead to the destruction of the forming aggregates, and therefore it requires strict control over the mixing time. The ejector here works as a jet-pump and improves both dosage and mixing processes (figure 1).

**Figure 1.** Ejector: 1 – intake chamber; 2 – nozzle; 3 – reagent intake pipe; 4 – suction pipe; 5 – ejector body.

### 2. Single phase model description and results

Single-phase model was used for the modelling, i.e. it was assumed that liquids flowing into both the intake reagent intake pipe and the water intake chamber have similar characteristics. Heat (energy) exchange was not considered for modelling. Turbulence was considered for modelling. Stationary operation mode was achieved after 60 sec of operation in the model.

The flow velocity (and its variation) is the main parameter characterizing the efficiency of an ejector as a mean of mixing reagents into the discharge waters.

Figure 2 shows velocity distributions for the given portion of the mixing chamber (length = 3 cm).

The X axis on the figure 2 represents the position of the ejector’s cross-section (the section plane is \( Z_0Y \), i.e. the cross-section goes perpendicularly to the section depicted on figure 1) for which velocities are given on the graph, starting from the left end of the mixing chamber. The velocities are modelled for the axis of symmetry of the flow. The Y axis represents the velocities, measured in m/s.

However, \( XZ_{053} \) (white) line depicts the magnitude of the velocity in \( X0Z \) cross-section (i.e. along the ejector’s length), for \( X=53 \) mm (i.e. directly at the entrance to mixing chamber).

The velocities are then estimated with a step of 3 mm starting from the entrance to the mixing chamber (its left end). Figure 2 clearly shows that \( XZ_{053} \) curve (red) does not stick to the ejector’s wall, as it is the position of the reagent intake pipe.

However, the single-phase model does not fully represent the processes going on the mixing chamber when discharge waters are mixed with the reagent added through the ejector’s pipe (which was originally designed for air intake), because in reality the reagent and discharge waters are distinct liquids with different characteristics, and therefore they should be represented as two different flows in
the ANSYS system. At this stage, there is no need to specify the reagent’s properties (this would require focusing on the concrete composition of the reagent), all we need is to set the model into “two flows mode” or dual-phase mode.

Figure 2. Velocity distribution along the mixing chamber.

3. Dual phase model description and results
The second model considered in this paper is dual phase model. Now we can analyze the homogeneity of the environment (liquid in our case). The homogeneity is directly related to the discharge water treatment efficiency, because more homogenic distribution of the flocculant in discharge water ensures better flotational treatment.

Figure 3 illustrates the volume distribution of liquids, i.e. phase composition of the flow.

Figure 3. Volume phase composition.
The composition presented on Figure 3 shows that an increase in mixing process intensity can be achieved by more than one way: the flows of both phases may be twisted together, e.g. by installing a separator of specific form on the entrance of the intake chamber; the intake velocity may be increased alongside with the length of the ejector. Alternative solutions may be similar to those described in [23-26].

4. Discussion of the results
According to (2), velocity gradient is one of the main parameters characterizing the mixing process. Table 1 illustrates the dependency between the velocity gradient value and the discharge water velocity at the intake.

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

| Water intake velocity, m/s | Flow, kg/s | Velocity, m/sec | N<sub>exit</sub>, % | Gradient values for velocity components, 1/sec |
|---------------------------|------------|----------------|----------------|-----------------------------------------------|
|                           |            |                |                 | V<sub>x</sub>max | V<sub>y</sub>max | V<sub>z</sub>max |
| 0,4 (7c)                  | 0,102      | 0,003          | 9,7e-06         | 0,919 | 5,829 | 1,645 | 2,76 | 12776 | 6188 | 7065 |
| 0,8 (14c)                 | 0,203      | 0,007          | 1,0e-05         | 2,115 | 11,634 | 3,304 | 3,16 | 24162 | 11931 | 14019 |
| 1,2 (21c)                 | 0,305      | 0,010          | 1,5e-05         | 3,310 | 17,452 | 4,962 | 3,29 | 36226 | 17920 | 20988 |
| 1,6 (28c)                 | 0,406      | 0,014          | 2,0e-05         | 4,487 | 23,273 | 6,620 | 3,35 | 48302 | 23906 | 27986 |
| 2,0 (35c)                 | 0,508      | 0,018          | 2,4e-05         | 5,655 | 29,094 | 8,277 | 3,37 | 60406 | 29897 | 34999 |
| 2,4 (42c)                 | 0,609      | 0,021          | 2,8e-05         | 6,811 | 34,920 | 9,934 | 3,39 | 72532 | 35896 | 42029 |

Data represented in Table 1 clearly show that the velocity gradient value (as well as the values of all its components) considerably depends on the water intake velocity. The ratio of the X component of the velocity gradient to its Y and Z components is approximately 2:1. It shows that the turbulation does not differ significantly direction-wise, what is likely an argument supporting good conditions for mixing of the reagent and the treated water.

5. Conclusion
The data obtained in this paper suggest the achievement of an efficient mixing process for introduction of the reagents to the treated water even at low water intake rates. Therefore, low-pressure pumps can be used; the mixing system could be simplified, and an enclosed mixing unit could be developed.

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