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ANALYSIS OF WATER INTAKE SCREEN'S PERFORMANCE UNDER VARIOUS CONDITIONS

ANALIZA PRACY CZERPNI W RÓŻNYCH WARUNKACH

Abstract

The article presents the problem of ichthyofauna protection in aquatic ecosystems. One of the possible solutions to protect the fish and fry in the water intakes is the use of properly designed water intake screens. The article presents the results of numerical calculations performed in Autodesk Simulation CFD software considering the performance of water intake screen under various conditions.

Keywords: water intake, water intake screen, ichthyofauna

Streszczenie

W artykule przedstawiono problem ochrony ichtiofauny w ekosystemach wodnych. Jednym z możliwych rozwiązań stosowanych w celu ochrony ryb i narybku w ujęciach wodnych jest wykorzystanie odpowiednio zaprojektowanej czerpni. W artykule zamieszczono wyniki obliczeń numerycznych wykonanych w programie Autodesk Simulation CFD uwzględniające pracę czerpni w różnych warunkach.

Słowa kluczowe: ujęcie wody, głowica ujmująca wodę, ichtiofauna

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1. Introduction

Water intake, which is the first element of a water supply system plays a fundamental role in its functioning. Therefore, it is especially important to design a proper water intake. Technical and economic aspects have to be taken into consideration as well as the fact that water intake may be a threat i.e. lead to injury or death of fish or fry inhabiting or migrating near the water intake. Potential losses of fish can be caused by its entrainment or impingement. Entrainment takes place when a fish is drawn into a water intake and cannot escape. Impingement occurs when an entrapped fish is held in contact with the intake screen and is unable to free itself. The degree of negative impact of water intake on the ichthyofauna depends on the number, size, arrangement of ichthyofauna and swimming ability of individuals, as well as the water velocity, inflow into the intake and depth at which the intake is installed. Other important factors are the type and size of water intake and the mesh size of a screen [1].

In order to protect fish and fry from entrainment, behavioural or physical barriers are installed in water intakes. The purpose of behavioural barriers is to deter the fish from getting to areas that may pose a threat to them. There are different types of behavioural barriers: louvers, light and sound behavioural devices, air bubble curtains, hanging chains, water jet curtains, electric fields and other [2, 3]. The barriers require an activity from the fish, and therefore their efficiency significantly depends on the ability of fish to swim.

Another, and the most popular, method of protecting fish and fry from entrainment by surface water intakes is the use of physical barriers [2]. These are the intakes equipped with special screens. The use of physical screens in place of water intake is recommended in case of small and medium size water supplies. The appropriate design of a screen is largely dependent upon the species and the size of fish requiring protection. Proper installation and maintenance/cleaning of the screen are also important and ensure satisfactory operation of the screen [1]. The screens can come in different shapes. These can be flat screens with circular or square cross section and box or cylindrical screen. According to [2] when a screen has round mesh holes, the size of mesh depends on the size of fish and fry and should be lower than 2.38 mm for fry and lower than 6.53 mm for fish with length greater than 60 mm. Usually the perforation of such screens is about 50–60% [2, 3], meaning that mesh holes represent 50–60% of the total screen area. The cylindrical screen is the most widely applied submerged screen concept. It consist of fully submerged screen modules placed at the intake and gravity diversion conduits. These designs may include a single screen module or multiple screen modules where larger diversion flow rates are required [4].

2. Material and methods

In order to check the performance of water intake screen under various conditions the Autodesk CFD software was used. The programme provides computational fluid dynamics (CFD) simulation, which is a simulation technique that mathematically simulates fluid flow and heat transfer.

CFD simulation works by iteratively solving mathematical approximations of the Navier-Stokes and Energy Equations to reach the solution. The software iterates these equations over the entire simulation model until an unchanging (converged) solution is attained.

The *k*-epsilon turbulence model is the most common model used in CFD to simulate mean flow characteristics for turbulent flow conditions. It is a double equation model which gives a general description of turbulence by means of two transport equations. It is typically more accurate than the constant eddy viscosity model, but more computationally intensive and slightly less robust. It is not as resource intensive as the RNG model (based on Re-Normalisation Group methods), but still provides good results. The *k*-epsilon turbulence model's equations are as follow:

For turbulent kinetic energy *k*:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij} E_{ij} - \rho\epsilon \tag{1}$$

For dissipation ϵ:

$$\frac{\partial(\rho\epsilon)}{\partial t} + \frac{\partial(\rho\epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial\varepsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}2\mu_t E_{ij} E_{ij} - C_{2\varepsilon}\rho\frac{\epsilon^2}{k} \tag{2}$$

where:
ρ – fluid density,
t – time,
x_i, x_j – coordinates,
u_i – velocity component in corresponding direction,
E_{ij} – component of rate deformation,
μ_t – eddy viscosity,
σ_k, σ_ϵ, $C_{1\epsilon}$, $C_{2\epsilon}$ – adjustable constants.

The first step is to create a geometry. It was assumed that the water intake screen is cylindrical. The water intake screen's (part of the screen where water enters) dimensions are as follows: diameter – 500 mm, length – 1000 mm.
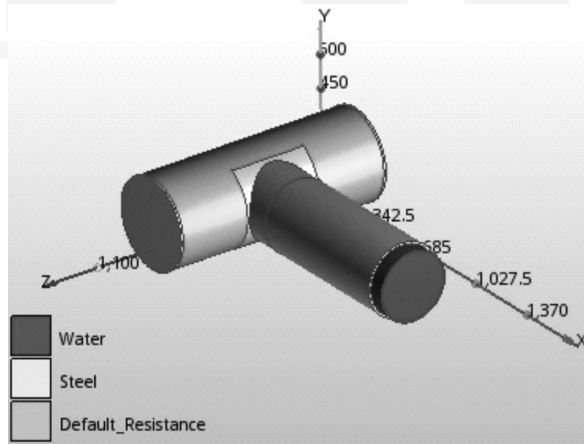

Fig. 1. Geometry model

Then a material of each part of the screen was determined and added. The screen material is stainless steel 304. As it does not affect the results of the simulation while it helps to reduce the analysis time, it was assumed that the resistance of the main part of the screen is 50% instead of taking into account huge amount of round mesh holes. Water flows into the screen through permeable surface (Default_Resistance in the Fig. 1), the rest part of the screen is impermeable. Outflow surface of the water is named "water" in the Fig. 1.

The next step is to define boundary conditions. It was assumed that the water intake screen is installed in the tank on the depth of 3 m. The appropriate pressure and the outflow from the screen were assumed as the boundary conditions.

The pressure was calculated as:

$$p_{tot} = p_0 + p_h = p_0 + \rho \cdot g \cdot h \tag{3}$$

where:

p_{tot} – pressure [Pa],
p_0 – atmospheric pressure – 101325 [Pa],
ρ – water density [kg/m^3],
g – gravitational acceleration, h – depth [m].

Simulations were done concerning that water is an incompressible fluid and that there is a steady state.

Simulations were done in order to check the inlet velocity and the approach velocity values according to the USA guidelines [2] presented in the Tab. 1.

Table 1

The acceptable inlet velocity and the approach velocity according to the USA guidelines [2]

Fish/fry size [mm]	Approach velocity measured 8cm in front of the screen [m/s]	Inlet velocity [m/s]
Fry < 60	≤ 0.06	≤ 0.15
Fish ≥ 60	≤ 0.12	

3. Results

There were simulations of two scenarios performed. In the first one it was assumed that outflow from the screen is 250 m^3/h, then the average inlet velocity equals to 0.15 m/s. The second one concerns outflow increased to 320 m^3/h.

The parameter especially important in terms of ichthyofauna protection is the approach velocity measured 8cm in front of the screen [2]. The results of approach velocity along Z-axis (X = 200, Y = 250, Z) are presented in the Fig. 2 for Scenario 1.
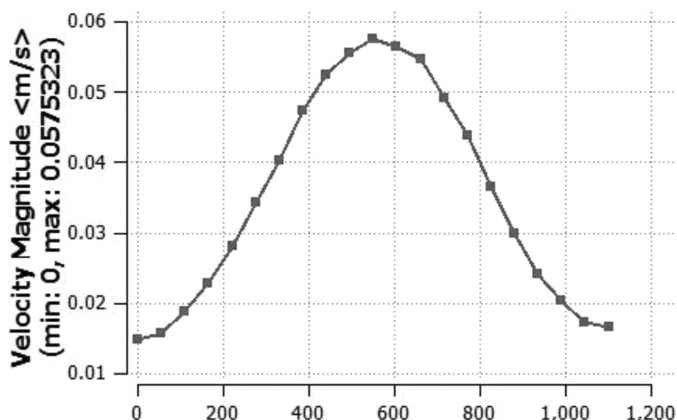
Fig. 2. Velocity distribution in Scenario 1 along Z-axis 8 cm in front of the screen

It can be seen that the maximum velocity value (0.058 m/s) is lower than the maximum acceptable approach velocities presented in the Tab. 1 for fish and fry as well.

The outflow from the screen is increased what is checked in Scenario 2. When the outflow increases to 320 m³/h the average inlet velocity equals to 0.18 m/s. The pressure and degree of perforation remains unchanged. The approach velocity distribution is shown in the Fig. 3.
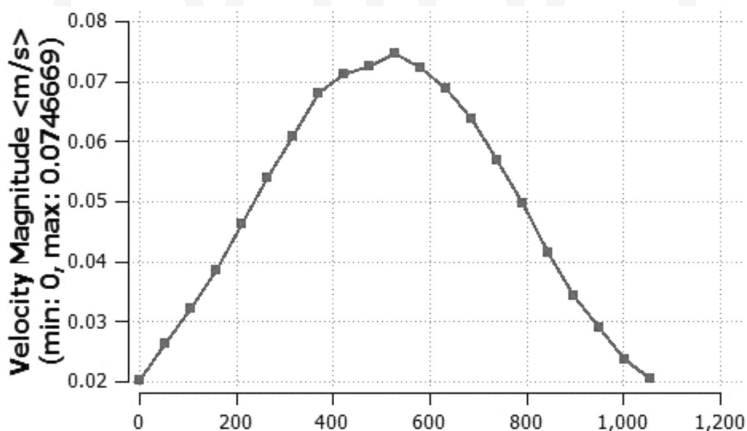

Fig. 3. Velocity distribution in Scenario 2 along Z-axis 8 cm in front of the screen

According to the obtained plot shown in the Fig. 3. the maximum velocity equals to 0.075 m/s. It can be said that the increased outflow is safe for fish (with minimal body length of 60 mm) as the velocity is lower than 0.12 m/s. A fry (with body length lower than 60 mm) could be endangered due to entrainment or impingement as the maximum velocity is higher than 0.06 m/s. It is impossible to determine a value of inlet velocity as the CFD programme provides averaged results of velocity on the screen's edge.

Additionally, the results of velocity distribution are shown in the Fig. 4., and Fig. 5. and the pressure drop is presented in the Fig. 6.
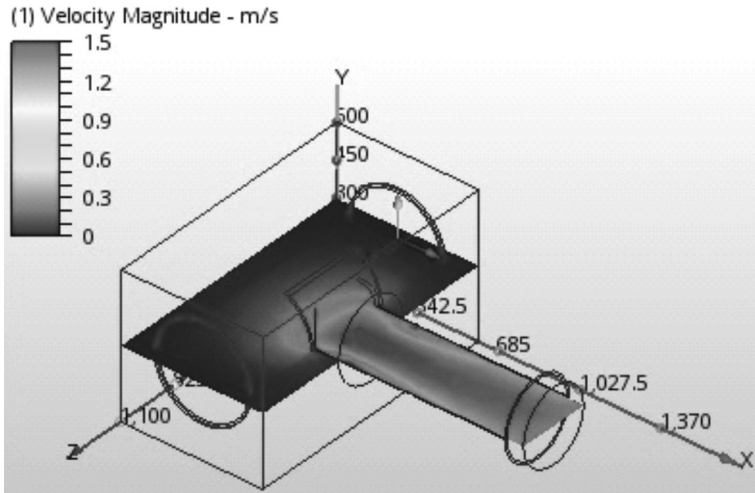

Fig. 4. Velocity distribution in Scenario 2

As expected the velocity is higher inside the manifold (discharge pipe), where it reaches 1.5 m/s unlike in the perforated, inlet part of the screen. In order to show the range of velocity more visible in this Scenario the plot of velocity value along X-axis (X, Y = 250, Z = 500) was done.
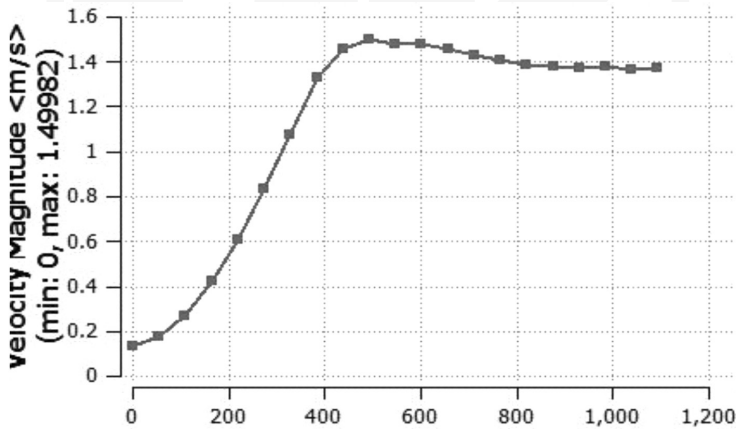

Fig. 5. Velocity distribution in Scenario 2 along X-axis

Another important parameter in the screen work's analysis is pressure. The Fig. 6. presents pressure drop inside the screen along X-axis (X, Y = 250,500).
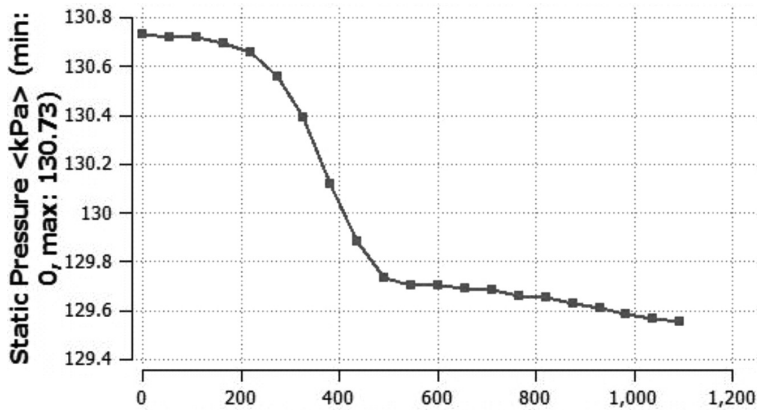
Fig. 6. Pressure drop in Scenario 2 along X-axis

It can be seen that the maximum static pressure is in the perforated, intake part of the screen and it exceeds 130.75 kPa. At the outlet of the screen static pressure is 129.58 kPa. The difference between inlet and outlet equals to 1.17 kPa which means that pressure head loss during flow is 0.12 m.

4. Conclusions

The numerical simulations allow to get qualitative and quantitative results of examined issues. Thanks to the simulation performed it is possible to determine the velocity and pressure distribution. The pressure distribution obtained in accordance with water intake capacity enables to determine pressure loss during the flow inside the screen.

Velocity and pressure are essential parameters in designing water intake screens protecting the fish and fry as well as preventing from retraction of ice, slush ice, debris from the bottom and larger polluting objects in a river.

The conditions presented in Scenario 1 are safe in terms of ichthyofauna protection. The results of velocity range in Scenario 2 are acceptable from hydraulic point of view. However, Scenario 2 can be dangerous for fry as the maximum approach velocity in front of the screen is higher than the acceptable one. Nevertheless, during the design of water intake screen, the size of the fish and fry inhabiting and migrating in the vicinity of the water intake is a key aspect and each case needs to be taken into consideration individually.

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