The Science of Water Screening

Custom design of water intake screens by using fluid and mechanical simulation cut development costs.

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Natural sources of water are vital to our way of life. We use water that either comes by way of public water supply systems, or directly from wells or springs. Water from lakes, rivers, or oceans has to be treated before it is usable, even if it is not intended for human consumption. Water for cooling or for generating steam in power plants and industrial processes has to be free of debris so as not to clog pumps, valves, pipes, or machinery.

Johnson Screens® is one of the most experienced manufacturers of steel screens to block debris without harming fish and other wildlife. Throughout this history, some of the varied applications for these screens have been in hydrocarbon processing, architecture, pulp and paper production, mineral mining, and food processing.

Figure 2: Johnson Screens' Ehrich Shaw next to a small intake screen.

Complications

You might think that there's nothing complicated about a wire screen, or that there is not much difference between a water screen and a window screen. But they are very different.

The first challenge is that the openings in the water screen have to be large enough for an unimpeded flow of water, but small enough to block debris. An additional problem is that if debris gets trapped in the openings, the water flow will slow down over time. It's also important to avoid environmental effects on the water life, so the flow has to be slow, smooth, and uniform. This is a challenge because this device has no moving parts — it's completely passive. To protect fish and other life, there should be no "entrapment"; that is, things becoming attached to the screen, and no "entrainment"; things being drawn to the screen.

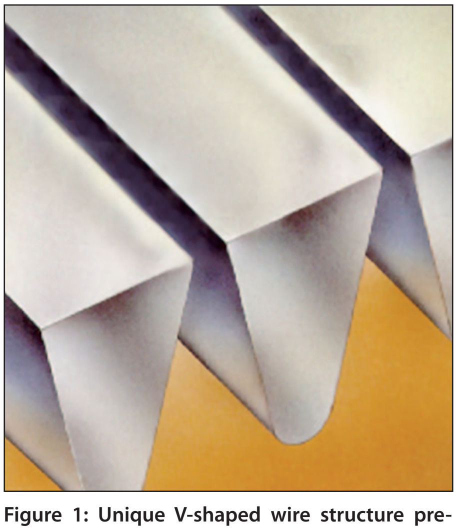

Figure 1: Unique V-shaped wire structure prevents clogging.

Solutions

Johnson Screens is the inventor of a unique V-shaped wire (Figure 1), with the surface facing the water having a flat face, and the sides tapering inward from the face to form the V. This has a number of advantages. There are only two points that contact particles, and since the space between the walls of the screen widens as the water travels through, particles will not become wedged in place. Also, the outside surface of the screen is very smooth and flat, which cuts down on abrasion to passing wildlife or other materials.

The intake screen is manufactured by a specially built machine that wraps the wire around a cylindrical support structure and automatically resistance-welds it at each point where the wire contacts the supports. A water bath cools the assembly during the welding process to limit the heat in order to prevent warping or uneven slot tolerances. These spacings are critical for achieving performance according to the design. Final assembly is then completed by skilled, certified welders.

Structure

The screen has to be designed so that the flow and structural criteria are achieved with a passive device — no moving parts. The basic structural element of the screen is a drum with the wire wrapped around it in the form of a helix. A single drum is generally used only where space or lifting capacity is limited. Most applications use a tee screen, which is constructed of two drums joined to a central outlet fitting.

After the wire design, the key component of the system is the internal, open-pipe flow modifier, which was developed more than 30 years ago and upgraded to a patented, multiple, but normally dual-pipe flow modifier in 1999. Its structure and dimensions are what enable passive control of the flow rate (Figure 3).

The third major component is the Hydroburst™ backwash system, which allows the screen to be cleaned by a short burst of compressed air without requiring the system to be shut down.

Key Design Factors

Each screen is custom-designed for a particular application, taking into account the typical characteristics of the debris, the turbulence of the water source, and the depth at which the screen will be placed. The screen has to be designed to effectively prevent solid particles from entering the user's water supply, while being nearly invisible to the flow. The velocity of the flow should be low enough so that there will be minimal influence on particles passing it by. This is achieved by maintaining the flow at a slow and constant rate, and keeping it uniform over the surface of the screen.

The distance from the screen for which it will have some effect on its environment is called the zone of influence, and should be as small as possible. The design of the flow modifier usually keeps this zone of influence to no more than half of the screen diameter.

Wire Design

The size of the wire can theoretically range from 0.020 to 0.191 inches (0.5 to 4.9 mm). The wire is selected based on its structural characteristics — the ability to withstand depth and impact loading — while providing enough open area for the desired flow. The screen must be designed to take into account the maximum allowable flow rate, which is usually determined by biology experts as being a safe velocity for water passing through the screen to allow fish to escape, and to limit entrapment and entrainment effects. The flow capacity of the screen is determined by multiplying the open area by the allowable average velocity.

"Each screen is custom-designed for a particular application."

Flow Modifier

The open-pipe flow modifier controls the flow rate through the screen. The dual concentric design is an improvement over the earlier single-pipe design in that it allows the same flow velocity with a 20 to 30% smaller intake. The cumulative velocity at the screen surface is controlled by the relative sizing and positioning of the two or more concentric tubes in the interior of the intake. Since the open area at the surface of the screen is so small, it has only a very localized effect on the flow acceleration. Most of the control is therefore achieved by the flow modifiers.

The flow curve (Figure 4) illustrates the typical variation in velocity along the length of the screen for the original single flow modifier and the new dual-pipe design (it is uniform around the circumference). The ideal profile would be a straight line from end to end. A measure of the deviation from ideal is the ratio of average to peak velocities (the ideal case being 1). The higher the ratio, the greater the ability to achieve higher flow rates with smaller screens. Smaller screens have less of a zone of influence and are usually more economical to implement — they require smaller pipes to connect to the water use point.

COMSOL Multiphysics Modeling

The details for each screen have to be designed for the particular application. The design has to take into account fluid dynamics and structural mechanics — a perfect problem for COMSOL Multiphysics, with its ability to model the interactions of these different elements.

Michael Ekholm, Manager, Applications and Product Development for Johnson Screens said, "The design and development of these screens was not accidental. It requires the ability to accurately predict the flow pattern in and around the screen (Figure 5). With a modeling tool such as COMSOL, we can use a variety of methods in this study. Depending on the requirements and flow capacities, this can vary between laminar and turbu-

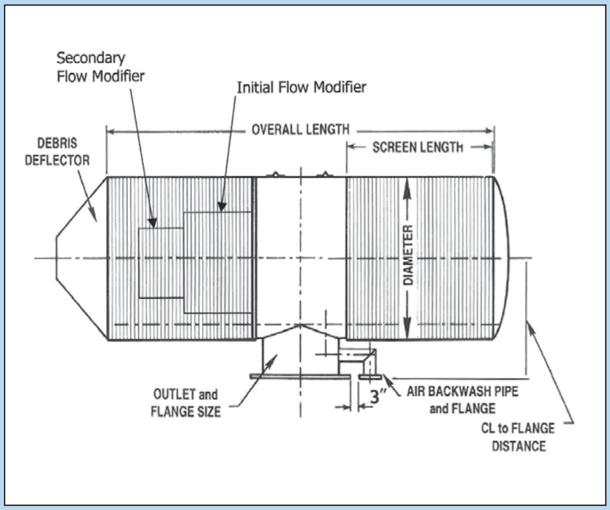

Figure 3: Key components of the screen assembly.

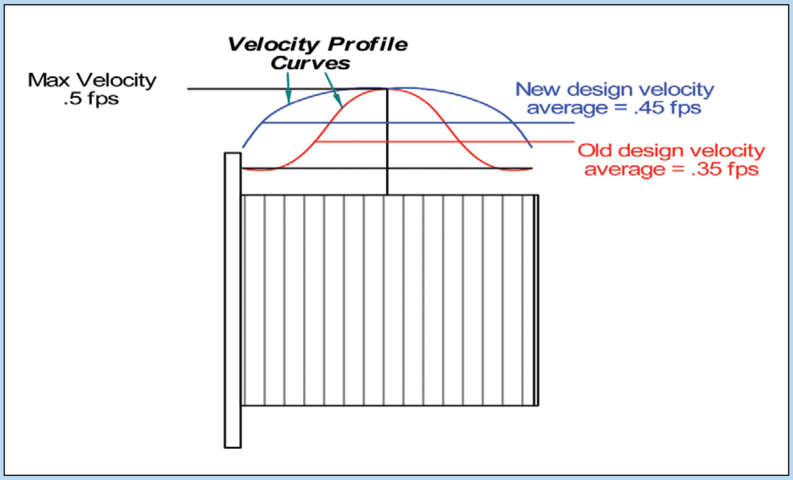

Figure 4: Comparison of the flow velocity distribution for dual-pipe versus single-pipe designs.

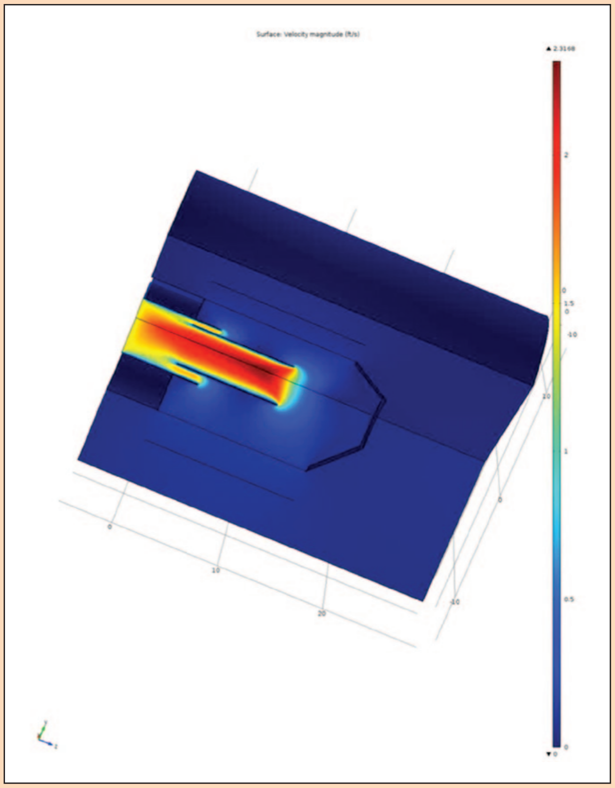

Figure 5: Multiphysics model of the velocity distribution. Flow is lowest surrounding the exterior of the screen and highest inside the screen within the dual-pipe flow modifier.

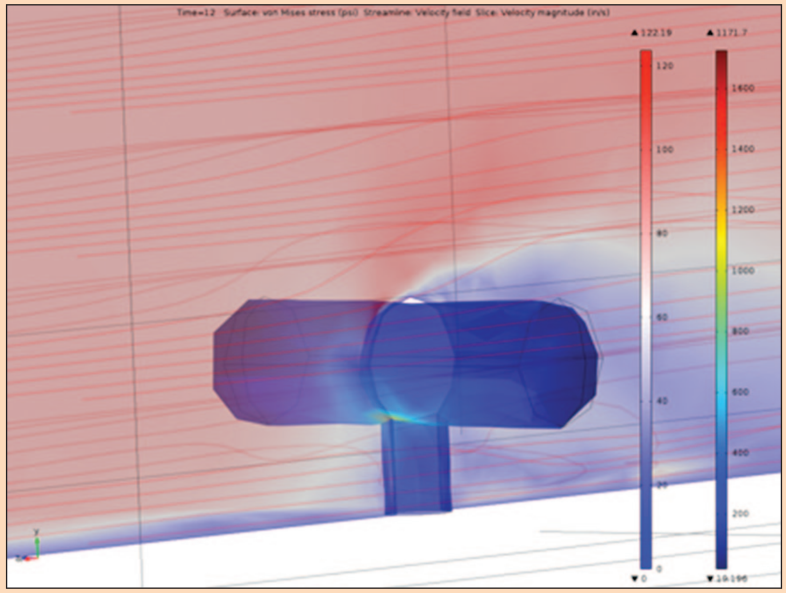

Figure 6: Multiphysics model of the combined effects of wave loading on flow and structural stress.

lent conditions. Changes such as extending the aspect ratio between the diameter and length of the screen, optimizing the flow performance, and adding new features such as a triple flow modifier are possible using modeling. Extensive costs in consulting and analysis were saved by implementing COMSOL as an in-house modeling tool."

Not only does it help in the design, but, as Ekholm explained, "The extensive graphing and solution illustration capabilities in the software allow the presentation of the predicted performance to be easily used in reports critical to permitting and acceptance documents."

Wave Loading

Wave loading is a problem that is particularly suited to modeling. Wave loading is the term given to cyclical surges of water acting on the screen, which not only causes changes in the impinging velocity and pressure, but can also vary in angle of action. COMSOL's built-in, time-dependent solvers and cyclical functions are ideal for handling this problem. The multiphysics software is used for modeling the structural problems caused by the wave loading. The resultant loads from a computational fluid dynamics (CFD) analysis for the wave models are applied to a shell/plate structural model of the intake. Key areas of stress concentration can be reviewed to make sure they are below the design stress, and to examine whether a cyclical load such as water waves can cause any fatigue issues (Figure 6).

Hydroburst Air Backwash System

The screens are periodically cleaned with a short burst of air stored in a receiver tank at the surface of the water. The timing and velocity of the air have to be calculated so that the resultant velocity at the screen surface is not excessive, but is enough to move debris off of the screen. The air introduced helps to float the debris away from the screen that has been pushed off. Fish will only be moved away from the screen as they would in a rapid stream or other natural water effect. A mechanical scraper or other mechanism could injure the fish by contacting them directly.

"What is of interest is the expansion of the air from the screen, to see if it will flow to an adjacent screen in the case modeled. With COMSOL, both the air expansion and the flow into the adjacent screen (zone of influence) can be modeled to provide a realistic view of the event," said Ekholm.

Multiple Uses of COMSOL Multiphysics

Multiphysics has not only been used for the initial design in this unusual application, but is used to model the complex interactions of fluid, air, and structure for the custom design of each application. It has been proven in tests to provide accurate results, thereby eliminating the need for actual physical modeling. ■

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