The Optimisation of Wastewater Treatment Systems using Adjoint Solutions for CFD-based Simulations

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stream

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1. Introduction

Traditionally, solid particles are removed from wastewater through the use of sedimentation tanks. This is a slow process that requires large structures, which are costly to build, both financially and environmentally in terms of their embedded carbon.

More recently, solid particles have been removed from wastewater through the use of vortex flow separators. This is a faster process that requires smaller structures, which are cheaper to build, both financially and environmentally, than their traditional counterparts.

The Swirl-Flo® is a vortex flow separator that has been developed by Hydro International. The aim of this project is to modify the shape of the Swirl-Flo, in order to optimise the concentration of solid particles captured in the separator.

It is intended to achieve this by doing the following:

- Modelling the flow of wastewater through the Swirl-Flo, using Computational Fluid Dynamics (CFD)
- Optimising the shape of the Swirl-Flo, using a process called the Adjoint Method.

2. What is CFD?

CFD is a branch of fluid mechanics that uses computational methods to solve fluid flow problems. The equations that describe fluid flow are often too complicated to be solved algebraically and, hence, numerical methods are employed, which are better suited to being solved on a computer.

In order to do this, the following are necessary:

- To have a virtual 3D model of the object in the computer. Figure 1 is a virtual 3D model of the Swirl-Flo, created using the meshing software Pointwise®.
- To create a mesh of the flow domain. Although the velocity and pressure are continuous, in CFD the governing equations are solved by discretisation; the domain is divided into numerous boxes (termed cells), making up a mesh, and the governing equations become a set of balancing equations for flow into and out of each cell. Figure 2 is a cross-section of the mesh.

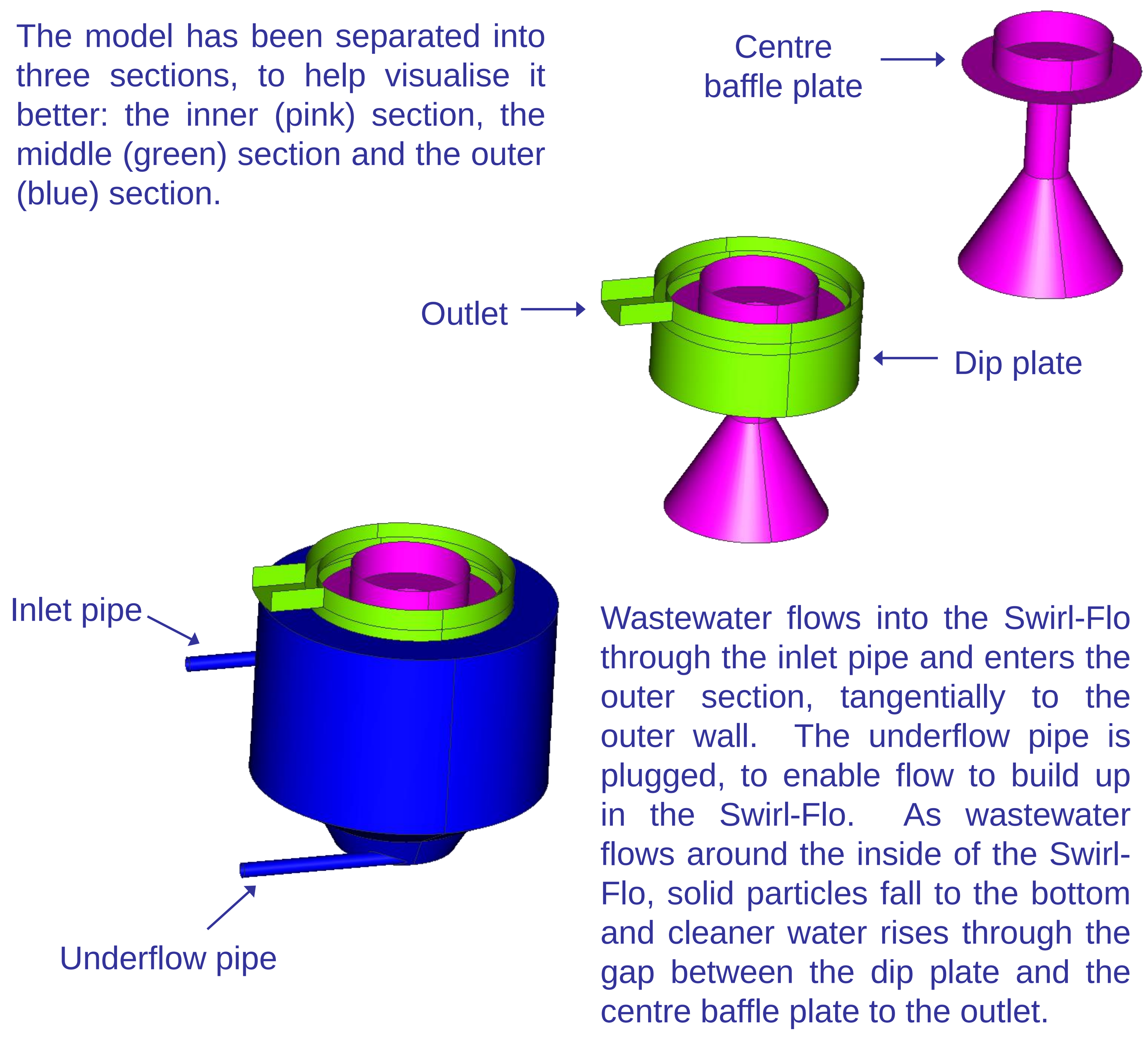

Figure 1 – Virtual 3D model of the Swirl-Flo

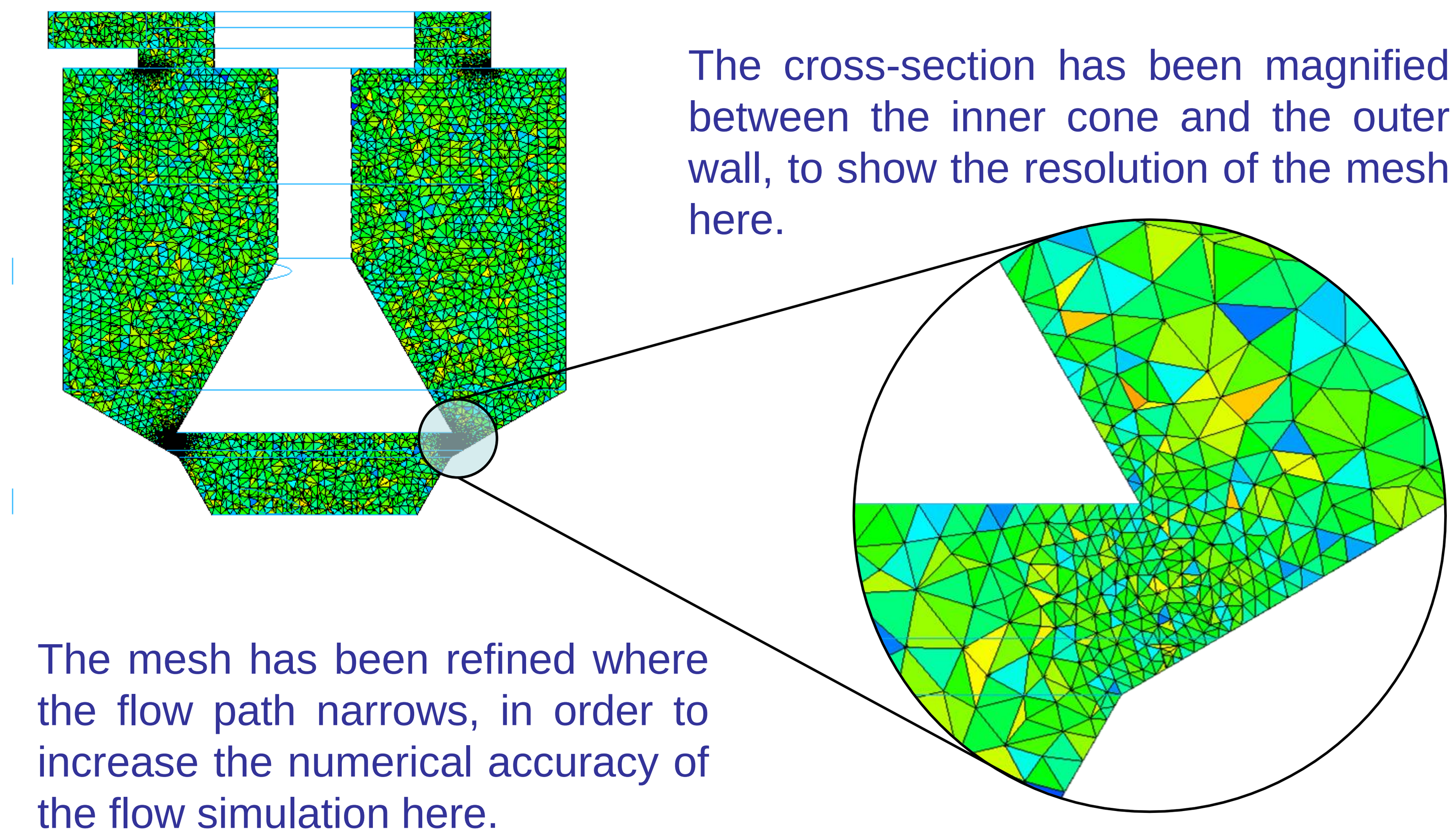

Figure 2 – Cross-section of the mesh

The CFD equations were solved for all cells in the mesh, using the CFD software OpenFOAM® and the k-epsilon turbulence model. Figure 3 shows two streamlines, traced from the inlet to the outlet of the mesh and coloured according to the magnitude of their velocity, U (m/s).

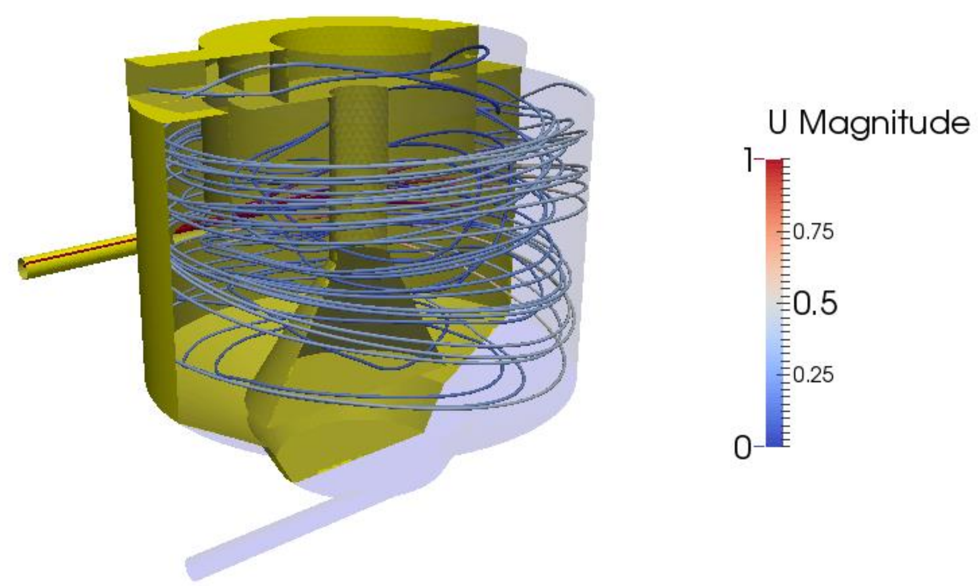

Figure 3 – Two streamlines, traced from the inlet to the outlet of the mesh, coloured according to the magnitude of their velocity, U (m/s)

3. What Next?

The next task is to simulate the flow of the solid particles in the Swirl-Flo and then to optimise the shape of the Swirl-Flo, so that the solid particles are separated from the wastewater as quickly as possible.

In order to do this, the settling velocities of the solid particles must be calculated in relation to the geometry of the Swirl-Flo. If this is done for all possible geometries, the optimum shape of the Swirl-Flo will be found that minimises the retention time of the wastewater in the separator.

The challenging part of this is that the mesh contains millions of cells and the CFD equations are computationally very expensive to solve. Repeating this process for all possible geometries would be prohibitive. However, the process can be accelerated if information about the gradients is available.

4. The Adjoint Method

The Adjoint Method is a way of computing gradients. In particular, it is very efficient at computing the gradient of one function with respect to many parameters, which essentially defines this problem: the function is the settling velocity of the solid particles and the parameters are the points in the mesh.

To summarise the process, the Adjoint Method computes the gradient of the settling velocity with respect to the mesh. The velocities and gradients are then passed to a gradient-based optimisation algorithm, which returns a new mesh with a better settling velocity. This process is repeated until the gradients equal zero, at which point the optimum geometry for the Swirl-Flo has been found.

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