# Analyzing a Malfunctioning Clarifier with COMSOL's Mixture Model

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**Abstract:** In wastewater treatment plants clarifiers are used to separate sludge and water. In this paper we analyze a malfunctioning clarifier with the mixture model of COMSOL Multiphysics. Because the description of sludge by wastewater engineers does not match with the mixture model, we propose a translation. With proper translation we are able to get model results that are reasonably close to measurements from the real clarifier. With the model we can explain the bad seperation of water and sludge in the clarifier. Engineers proposed several measures to improve the performance of the clarifier. All measures were applied in the model. It appears that a slight increase of the flock diameter of the sludge is the most effective measure.

**Keywords:** mixture model, sedimentation, active sludge, wastewater treatment

## 1 Introduction

In wastewater treatment plants (WWTP) the influent wastewater is treated with the so-called active sludge process in combination with sedimentation in clarifiers. Active sludge consists of biological micro-cultures (bacteria) that is able to remove nitrogen and phosphorous from the water. After treatment the active sludge needs to be separated from the water before the water leaves the plant, such that the active sludge can be re-used and clear water flows into the environment. Separation of active sludge and water happens in a clarifier, usually a large circular tank with low flow velocities that allow the sludge, which is heavier than water, to settle on the bottom, where it is removed for re-use. Clear water floats over the top at the outer boundaries of the tank.

Figure 1: The clarifier at the wastewater treatment plant.

A certain Dutch wastewater treatment plant has serious problems with one of its clarifiers. Large amounts of sludge leave the clarifier with - what is supposed to be - clear water at the outer boundaries of tank. The number of suspended solids exceeds the desired number with a factor 4 and the active sludge that is tapped for re-use contains too much water. Witteveen+Bos has been asked to detect the causes for this malfunction and to propose measures to improve the performance of the clarifier. To find out what causes the problems and to verify the proposed measures, the flow in the clarifier was analyzed with COMSOL Multiphysics 3.4. The malfunctioning clarifier at study is depicted in Figure 1.

In this paper we describe the model that we used and the outcome of the analysis.

## 2 Modeling the Clarifier with COMSOL Multiphysics

The clarifier in the WWTP is circular. However, the inner part of the tank is in use for a different step of the process of wastewater treatment. The actual clarifier therefore has the shape of a torus. The bottom has a slight slope towards the centre of the tank.

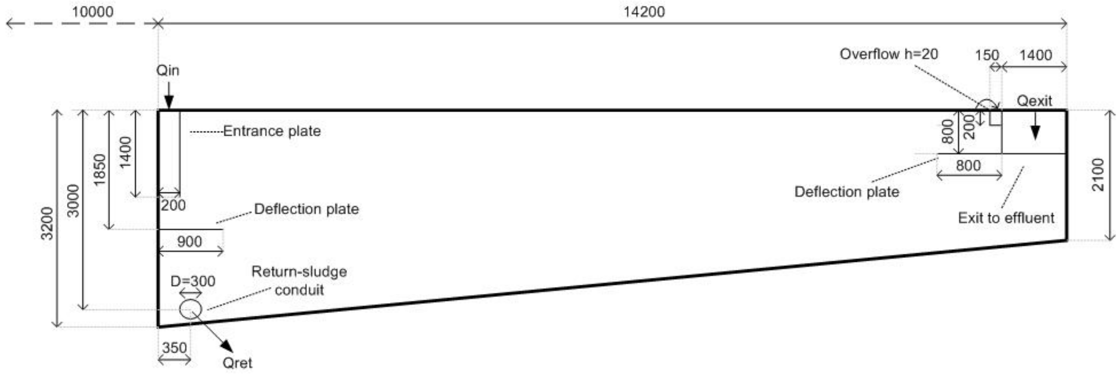

Figure 2: Dimensions (in mm) in a cross section of the clarifier

Figure 2 is a cross section of half the tank. The mixture of water and sludge flows in from the left at the top, clear water flows out at the right and sludge is removed by a conduit that rests on the bottom in the left corner. Deflection plates are present at entrance and exit.

## 2.1 Governing Equations

The flow in the clarifier was computed with the mixture model that is part of the Chemical Engineering module of COMSOL Multiphysics 3.4. The mixture model is able to compute the flow for a mixture of two liquids or a liquid and a solid. The model combines the k-epsilon turbulence model for the main flow with equations for the transport of the dispersed phase and the relative velocity of both phases. Because of the torus-shape of the tank, the model is applied in a 2D geometry with axial symmetry.

Unfortunately the application of the mixture model to the reality of the clarifier is not as straightforward as it might seem. The difficulties are partly caused by the terminology used by wastewater engineers that needs translation to the terms of the model and partly by uncertainties in physical quantities.

## 2.2 Sludge: Particle or Fluid?

One of the important questions that need to be answered is: should active sludge be considered as a particle or as a fluid. Wastewater engineers usually describe the "sludge content" in the water in terms of "grams dry solids per liter" (DS). This suggests that sludge should be considered as a solid particle floating in the water. However this description causes troubles in the mixture model, since weight and the density of the particle has to be determined. It is hard to find consistent and realistic values for both quantities in literature. Moreover in practice sludge is non-homogeneous; it consists of several types of particles with different weigths and densities. An even more import consideration is the fact that the sludge particles clit together and form flocks that can hold large amounts of water. To avoid al these troubles we will consider sludge as a fluid. The model requires specifying the diameter of the sludge flocks in water, which varies from 0.2 to 2.0 mm accoording to literature.

## 2.3 Translation of SVI to Volume Fraction

Next to sludge content wastewater engineers use the sludge volume index (SVI) to describe the settleability of active sludge. The SVI is defined as "the volume in mililiters occupied by one gram of dry solids after the aerated mixed liquor settles 30 minutes". It is a measure for the settling properties of the sludge particles. In general a smaller SVI means that the flocks carry less water, so they will sink more easily and therefor sludge and water can be separated more easily. Normally, the SVI for activated sludge varies from 80-200 ml/g ds, with optimal settleability between 80 and 120 ml/g ds. The SVI needs to be translated to the volume fraction that is used in the mixture model at the inflow.

The natural way to do this is

$$\begin{aligned}\phi_{in} &= SVI \cdot DS_{in} \\ &\approx 60\ [ml/g\ ds] \cdot 2.5\ [g\ ds/l] \\ &= 0.09\ [1].\end{aligned}$$

## 2.4 Uncertainties in Physical Quantities

Unfortunately there is lack of information on the exact physical conditions in the clarifier. Not all relevant physical quantities are known and few measurements are available to calibrate the model. We have knowledge about the controlled variables like the inflow ($Q_{in} = 2,667 m^3/h$) and the return-sludge flow ($Q_{ret} = Q_{in}/4$). Furthermore a time-average value is given for the amount of sludge at the outflow: $DS_{out} = 80\ mg\ ds/l$ ($\phi_{out} = 0.0028$). The desired value is four times smaller: $DS_{out} = 22\ mg\ ds/l$ ($\phi_{out} = 0.00079$).

Since there is no information about the density and the flock diameter of the sludge, we use reasonable values from literature ($\rho_{sludge} = 1,025\ kg/m^3$, $d = 0.8\ mm$). Moreover we assume that sludge and water have the same viscosity (both $\nu = 10^{-3}$). In the mixture model we use a volume average viscosity, hence there is no maximum packing density involved in the computation. The Schiller-Naumann model is used to compute the slip velocity between sludge and water.

## 2.5 Setup of Numerical Experiments

The mixture model for the clarifier is solved via a transient simulation. Initially the tank is filled with pure water and in approximately 3 hours the volume fraction of sludge at the inflow is increased to the given value $\phi_{in} = 0.09$.

Wastewater engineers at Witteveen+Bos proposed several measures to improve the performance of the clarifier. The effect of the measures is verified in the mixture model by changing several parameters: the density of sludge $\rho_{sludge}$, the flock diameter $d$ and the position and slope of the deflection plates.

# 3 Results

In all model runs the tank reaches equilibrium after approximately 48 hours. With the chosen values for density ($1,025\ kg/m^3$) and flock diameter ($0.8\ \ mm$) we get an amount of sludge at the outflow of $460\ mg\ ds/l$, which is more than six times the measured average value of $80\ mg\ ds/l$. The flow pattern at equilibrium and the distribution of sludge in the tank is depicted in Figure 3. The streamlines show a short circuit flow from the inflow to the return-sludge conduit. It is very likely that this short circuit flow causes the high levels of dry solids at the outflow. This is supported by the observation that the short circuit flow only occurs after 36 hours. The first one-and-a-half day the flow is more like Figure 4 (more about that figure later), then in a short period of time the flow changes into the given flow pattern. The transition leads to a slight decrease of $DS_{ret}$, however all particles eventually have to leave the tank, so the increase of $DS_{out}$ is sever.

It is very likely that the short circuit flow is caused by the torus-shape of the tank. In a more common circular clarifier the mixture leaves the deflection plates with a higher velocity. The flow has more momentum; hence it will not sink immediately as happens in the torus-shaped tank.

Another disadvantage in the design of the tank is the position of the return sludge conduit. The transition of the flow pattern as observed is probably triggered by the accumulation in the corner nearby the conduit.

Even though it would probably be very effective, it is extremely expensive to change the geometry of the tank. The same holds for adaptations to the return-sludge conduit. So other, cheaper measures to change the flow pattern had te be found. Unfortunately the flow pattern appears to be quite persistent. Small changes to the geometry did not help. The deflection plates were moved in horizontal or vertical position, the length and slope was increased, but there was no significant reduction of $DS_{out}$.

Fortunately the two other measures appeared to be effective in the model. An increase of the sludge density to $1,050\ kg/m^3$ or an increase of the flock diameter to $d = 1.0\ mm$ diminishes $DS_{out}$. Of these two measures an increase of the flock diameter is most effective: $DS_{out}$ becomes $10\ mg/l$ which is below the target value. One might wonder if it is possible at all to change these physical properties of the sludge. The answer is: yes, flock forming can be altered by adding certain chemicals to the mixture before it enters the clarifier. Better packing of sludge particles results in higher densities and stimulation of growth of flocks leads to an increase of the flock diameter. In Figure 4 one finds the flow pattern and the distribution of sludge in the clarifier for $rho = 1,025\ kg/m3$ and $d = 1.0\ mm$. The flow pattern differs a lot from the pattern in Figure 3, especially the short circuit flow disappeared.

## 4 Conclusions

Even though there was lack of information on the exact physical parameters in the real clarifier, it seems to be possible to build a proper model using the mixture model of COMSOL Multiphysics. The proposed translation of ”sludge volume index” and ”sludge content” to a volume fraction of sludge appears to be a reasonable choice. At least the modelled clarifier suffers from the same high number of dry solids at the outflow.

According to the model, the most effective measures are an increase of sludge density and diameter. Changes to the deflection plates do not help.

## References


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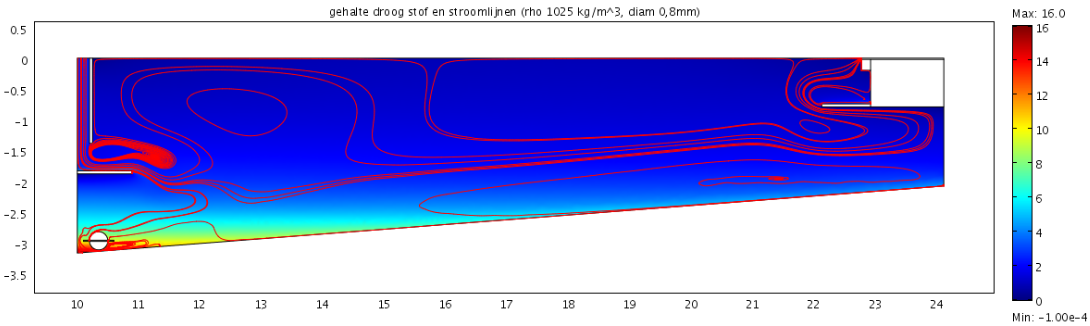


Figure 3: Suspended solids (g/l) and streamlines in the clarifier at equilibrium with flock diameter 0.8mm

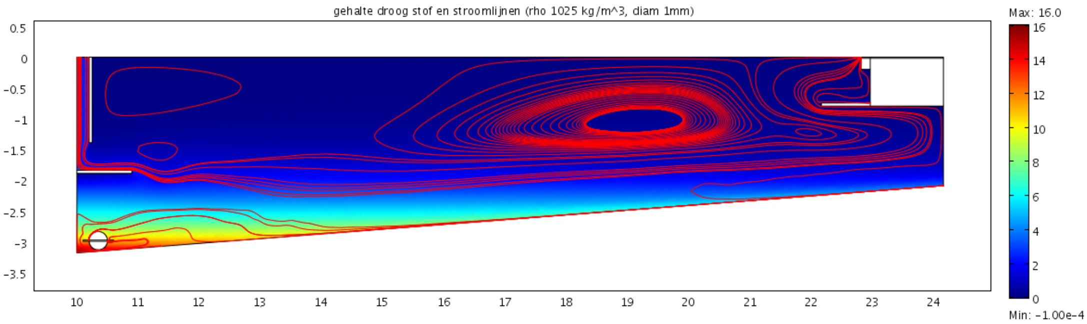


Figure 4: Suspended solids (g/l) and streamlines in the clarifier at equilibrium with flock diameter 1.0mm