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Numerical Model for Mist Separators

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ABSTRACT

This work describes a numerical model developed based on operating horizontal mist separators at Hellisheidi Power plant. The measurement data are observed by the production capacity from the separators. In this work the comparison between the measurement data from the observation and the numerical results used to verify the model. This works aim to develop an accurate model for separators in order to be able to design more efficient separators for future power plants.

1. INTRODUCTION

Two-phase separators (mist separators) are oriented either vertically and horizontally in geothermal industries. In this study, horizontal mist separators at Hellisheidi Power plant are considered for modeling.

In Two phase separator (gas-liquid), liquid falls to the bottom of the vessel and withdraw. The vapor (gas) moves upwards with reduced entrance velocity to minimize the droplet contain of the stream and exits from the end or middle (in the mirror type) of the vessel.

A two phase separator might consist simply of an empty vessel, which causes the fluid velocities in the entering pipe to be reduced be enlarging the cross-sectional area of flow. Usually, in order to increase the efficiency, separator includes the internal parts. The internal parts of the separators can be categorized as below (Figure 1): (Stewart & Arnold, 2008)

Primary separation section (entrance): for separating the bulk of the liquid as well as large droplets of liquid quickly from the gas stream, and remove gas from the liquid.

Secondary separation section: for removing smaller liquid droplet by gravity settling.

Liquid separation section: for removing gas bubbles which may remain with the liquid.

Mist extractor: for removing the remaining liquid droplets that did not settle in the secondary section which can cause to reduce the diameter of the vessel.

Vortex breaker: prevents potential pump suction problems.

There is different design and arrangements for each category that can cause to improve the efficiency of the vessel and finally cause to have higher quality in the output gas as well as the output liquid.

For the Horizontal separators that operating in this power plants, the entrance section is simply the inlet pipe. Other configurations (bended inlet pipe) has been modeled to compare the efficiency of different configurations.

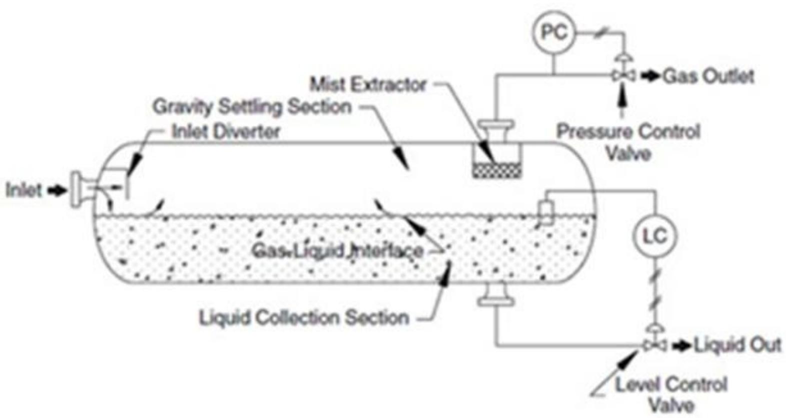


Figure 1: Schematic Horizontal steam separator (Stewart & Arnold, 2008)

2. OBSERVATION

Since observations in this study has been done in Hellisheidi Power Plant, here we will just present the measurement results.

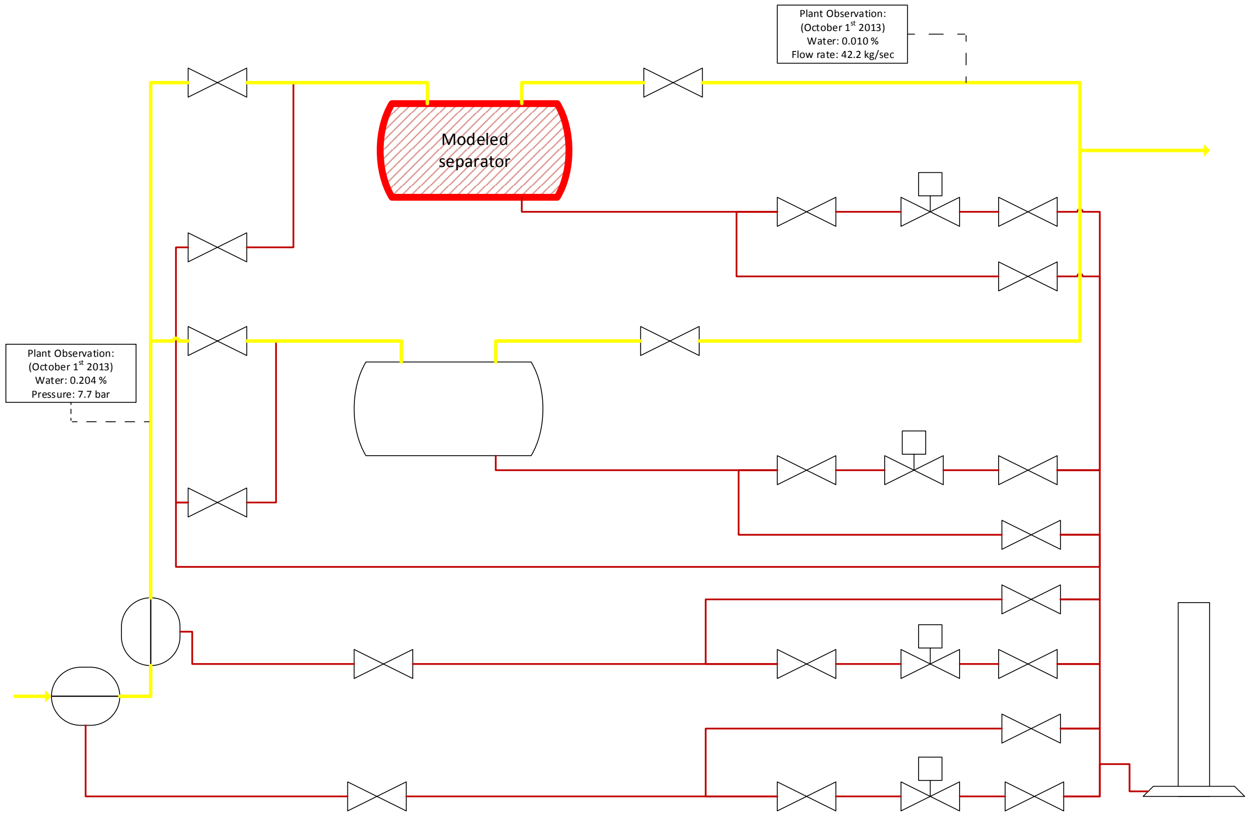


Figure 2: Flow Diagram of Hellisheidi Power Plant Unit 2

As it has been showed in Figure 2 the flow (mixture of steam (0.796 volume fraction) and water) is entering to unit through yellow pipes and in different locations (especially separators) steam's water contain is reducing where finally it is 0.01 water in the steam flow.

Measurements has been done in two locations before and after separators (as showed in flow diagram Figure 2). The outlet steam is use to rotate turbine and extracted water is injecting to the well again.

3. CALCULATION MODEL

Figure 3 shows a schematic view of a horizontal separator with operating size based on technical data from Hellisheidi Power Plant ("Moisture Separator," 2008). Both phases (water – steam) are considered as continues phase in the inlet section. Since volume fraction of water in inlet flow is about 20 percentage (Steam Quality Measurmen>, 2013), after entering to the separation section and passing through inlet section and decrease in momentum as well as sudden increase of vessel diameter and phase change, only small droplets of water will remain in steam stream.

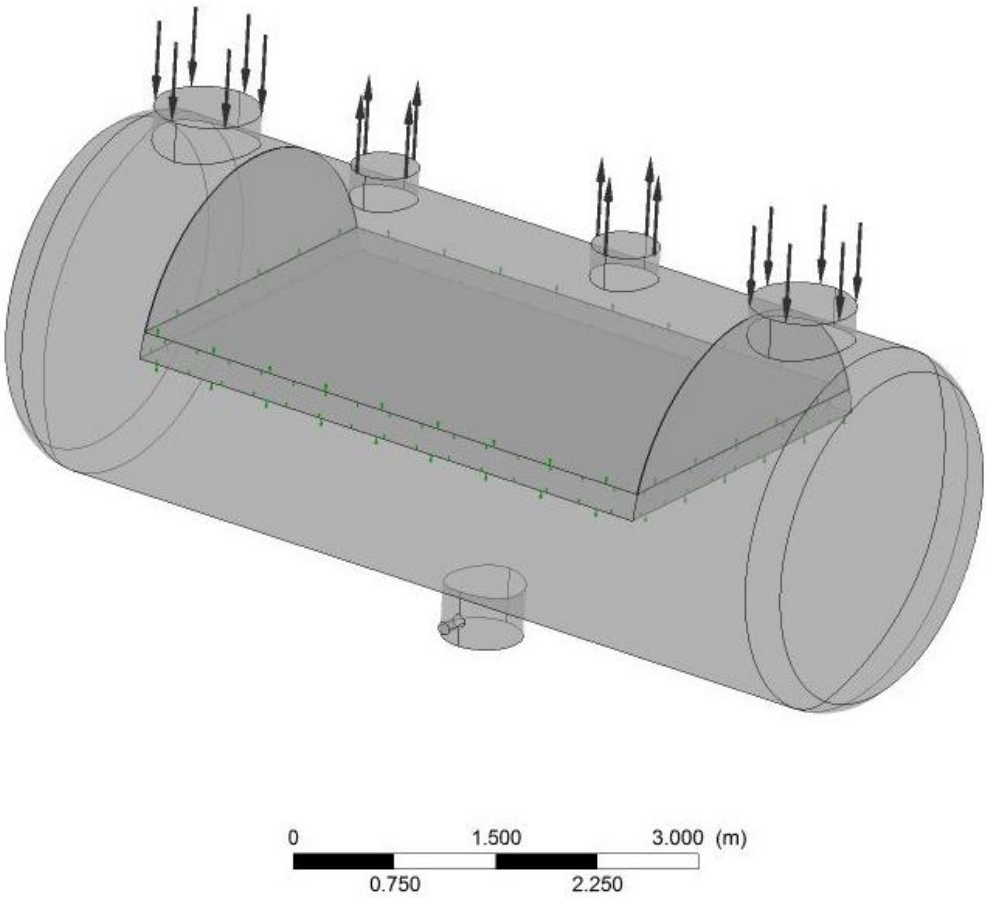


Figure 3: Horizontal mist separator (Sized based on operating separators at Hellisheidi Power Plant)

Appreciably amount of water droplets will settle downs to the liquid surface in the separation section. Remained droplets which their size are depends on the length of the vessel, will remove in mist extractor which wire mesh is used as mist extractor. Since total inlet volume fraction of liquid phase is about 20%, after inletting to the vessel volume fraction of the droplets is much less than 5% (Su, Huang, & Wang, 2005). In such case, droplet can be consider isolated. With considering droplet isolated means the steam stream influences droplets with drag and turbulence, but droplet cannot influences the main stream. Since steam stream is a continues flow, it can be describe by solving the time-averaged Navier-Stokes equations, while liquid phase which considered as discrete phase (in the separation section) is solved by tracking droplets through the resolved flow field.

3.1 Continuous Phase

In the separation section which steam stream is the continuous phase can be described by equations for the conservation of mass and momentum. So, the governing equations are as below:

Continuity equation:

$$\boldsymbol{\nabla . V = 0} \tag{1}$$

And momentum equation can be describe as:

$$\overbrace{\rho\left(\underbrace{\frac{\partial V}{\partial t}}_{\substack{Unsteady\\acceleration}} + \underbrace{V.\nabla V}_{\substack{Convective\\acceleration}}\right)}^{Inertia\ (per\ volume)} = \overbrace{\underbrace{-\nabla p}_{\substack{Pressure\\gradient}} + \underbrace{(\mu+\mu_t)\nabla^2 V}_{Viscosity}}^{Divergence\ of\ stress} + \underbrace{f}_{\substack{Other\ body\\forces}} \tag{2}$$

In order to simplify the model, equations had been reduced to one dimensional. The continuity and momentum equations in one dimensional system will be:

$$\rho\left(\frac{\partial u_a}{\partial t} + \frac{\partial u_a u_b}{\partial x_b}\right) = -\frac{\partial p}{\partial x_a} + \frac{\partial}{\partial x_b}\left[\mu_{eff}\frac{\partial u_a}{\partial x_b}\right] \tag{3}$$

$$\frac{\partial u_a}{\partial x_a} = 0 \tag{4}$$

Where u is the Cartesian velocity components of phases (i=a,b), x, p and μ_{eff} are standing for coordinate axis, pressure and effective dynamical viscosity, respectively. The effective dynamical viscosity defined as follow:

$$\mu_{eff} = \mu + \mu_t \tag{5}$$

Where μ_t stands for eddy viscosity. The eddy viscosity defined as:

$$\mu_t = \rho C_\mu \left(\frac{k^2}{\varepsilon}\right) \tag{6}$$

Where ε and k are representing energy dissipation rate of turbulent flow and turbulence kinetic energy, respectively. The eddy viscosity defined based on standard k-ε model which used in this problem.

Turbulent kinetic energy equation is as follow:

$$\rho\left(\frac{\partial k}{\partial t} + \frac{\partial u_a k}{\partial x_a}\right) = \frac{\partial}{\partial x_a}\left[\left[\mu + \frac{\mu_t}{\sigma_k}\right]\frac{\partial k}{\partial x_a}\right] + \frac{\partial u_a}{\partial x_b}\left[\mu_t\left[\frac{\partial u_a}{\partial x_b} + \frac{\partial u_b}{\partial x_a}\right]\right] - \rho\varepsilon \tag{7}$$

And below equation represents dissipation rate:

$$\rho\left[\frac{\partial \varepsilon}{\partial t} + \frac{\partial u_a \varepsilon}{\partial x_a}\right] = \frac{\partial}{\partial x_a}\left[\left[\mu + \frac{\mu_t}{\sigma_k}\right]\frac{\partial \varepsilon}{\partial x_a}\right] + \frac{\partial u_a}{\partial x_b} C_{\varepsilon l}\frac{\varepsilon}{k}\left[\mu_t\left[\frac{\partial u_a}{\partial x_b} + \frac{\partial u_b}{\partial x_a}\right]\right] - \rho C_{\varepsilon 2}\frac{\varepsilon^2}{k} \tag{8}$$

3.2. Equation of Motion for Droplets

Since each droplet considered isolated, the drag force acting on each droplet can be determined as bellow:

$$F_D = C_D A_D \rho_g \left(\frac{V^2}{2g}\right) \tag{9}$$

Where C_D stands for drag coefficient, A_D cross section area of droplet, ρ_g for gas density and V is terminal velocity of the droplet.

There are several different equations that use to calculate the drag coefficient base on droplet's Reynolds number. In this condition Li-chun et al. (Li-chun, Zhi-jiang, Qiang, & Jing-fei, 2009) suggested using of

$$C_D = \left[0.63 + \frac{4.8}{\sqrt{\rho_g(u_g - u_d)D_d/\mu_g}}\right]^2 \tag{10}$$

Where u_g, μ_g and ρ_g are gas's velocity, dynamical viscosity and density, respectively. U_d, ρ_d and D_d are standing for droplet's velocity, density and diameter, respectively.

Applying Newton's second law, with considering gravity force will gives below equation for droplet:

$$\frac{du_d}{dt} = \frac{3}{4}\frac{\rho_g}{\rho_d}\frac{C_D}{D_d}\left|u_g - u_d\right|\left(u_g - u_d\right) \tag{11}$$

Using the above described model the separator efficiency was estimated by calculating the volume fraction of the water droplets at the steam outlet section base on different configurations that will be discuss in next section. For both vertical and horizontal separators, same sizing selection standard has been considered which will be describe in next section. Also, for all cases, operating condition has been consider as the same condition of under study cases.

3.3. Separation Mechanism of Droplets

Since inlet water stream considered as a continues flow, in the inlet section, depends on configuration the first step of separation will occurs which is broken droplets from the liquid film due to interfacial shear stress.

In the second step, droplets would be broke up by impacting on the liquid film. And finally, broken droplets caused by interaction with continuous phase (steam stream). In case of interaction between droplets with continuous phase, the broken droplets can be estimate by following Weber number:

$$We_d = \rho_g\left(u_g - u_d\right)^2\frac{d}{\sigma_d} \tag{12}$$

Where We_d is Weber number of droplet; ρ_g, u_g are density and velocity of the gas, respectively. d is stands for droplet's diameter and u_d for the droplet velocity and finally, σ_d is surface tension of water.

The critical value of We_d is about 13, above which the droplets suspending in the continuous phase would break up.

Since, water enters to the separator as a liquid film, broken droplets from liquid film can be determine by film weber number as below:

$$We_f = \rho_g\left(u_g - c\right)^2\frac{\delta}{\sigma_d} \tag{13}$$

Where We_f is weber number for liquid film; c is wave velocity of liquid film, δ is film thickness. And the critical value for the film weber number is about 1.5, above which liquid film would break up.

4. SIMULATION OF HORIZONTAL SEPARATOR

Simulation of a horizontal mist separator were performed with the models described in preceding sections. The time step used in the simulation was $\Delta t = 10^{-4}\ sec$. In present case, we used geometry based on technical data available from power plant.

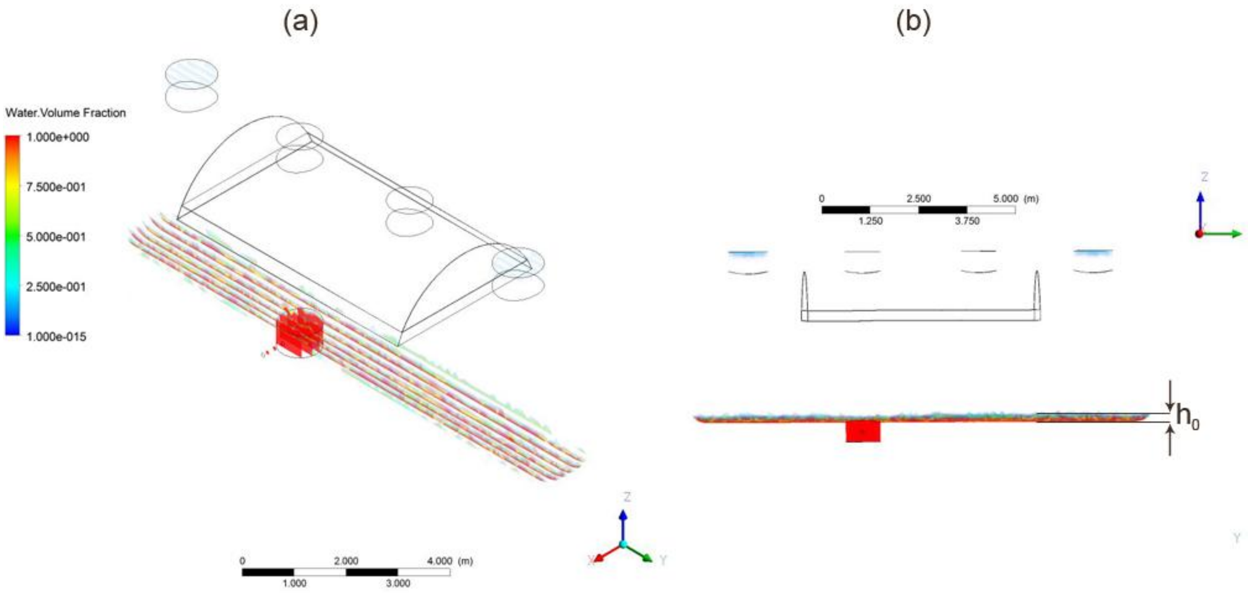
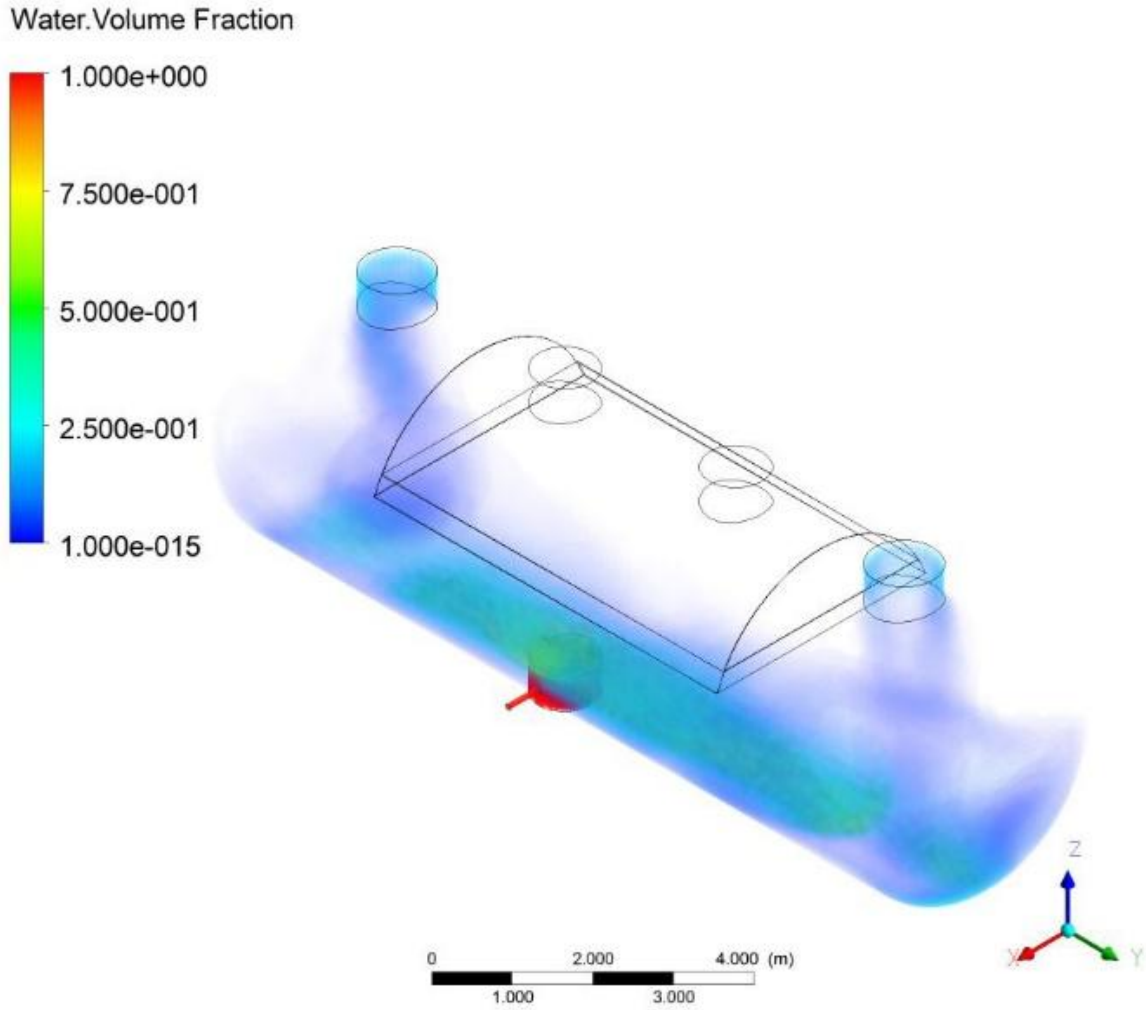


Figure 4: Initial condition of the mist separator a) isometric view b) h_0=10 cm is the initial height of the water inside the separator

Separator filled with pure water to a height of h_0, as shown in Figure 4. The surface tension coefficient of water was $\sigma_d = 0.038\ {}^{N}/_{m^2}$. The surface of the water was flat at the beginning of the simulation as shown in Figure 4b. Inlet velocity of the flow, 0.204 water and 0.796 steam, is around 2.3 m/s.



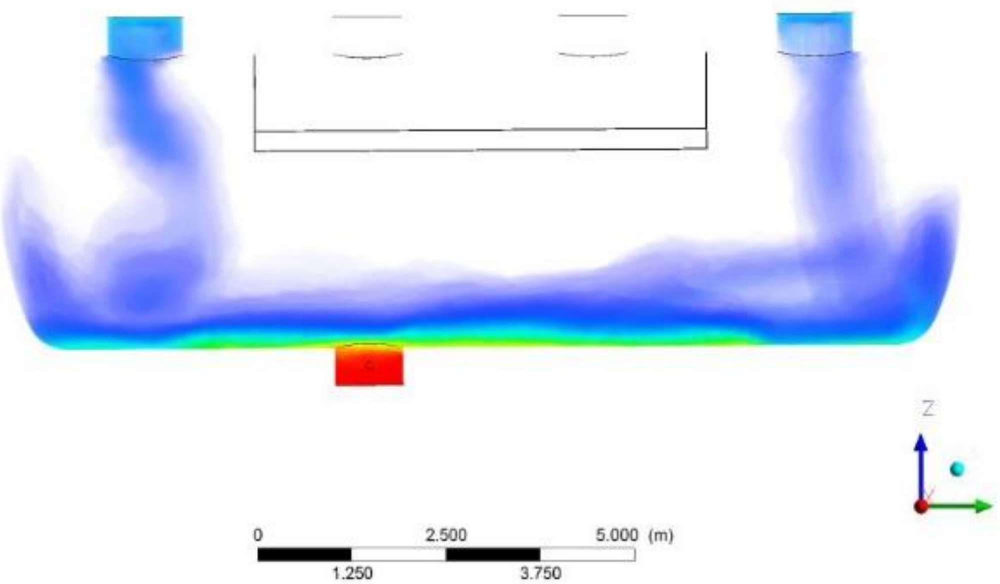


Figure 5 shows water volume fraction at t = 60 s. Figure 6b and c illustrates water quality at steam outlet cross section at the same time. The insets are representing an isometric view of the level section position. Outlet water quality at the steam outlet as shown in Figure 6 is less than 0.05%, which is in a good agreement with measurements that reported from Hellisheidi Power Plant.

5. CONCLUSIONS

A horizontal mist separator with same geometry as the operating separators at Hellisheidi Power Plant has been modeled as showed in Figure 3. A CFD model developed to predict water volume fraction at the steam outlet.

Simulation results were in the good agreement with the measurement results from the power plant (water volume fraction is less than 0.05 at outlet) as shown in Figure 6. This model can be used for different geometries in order to design more efficient separators for future plants.

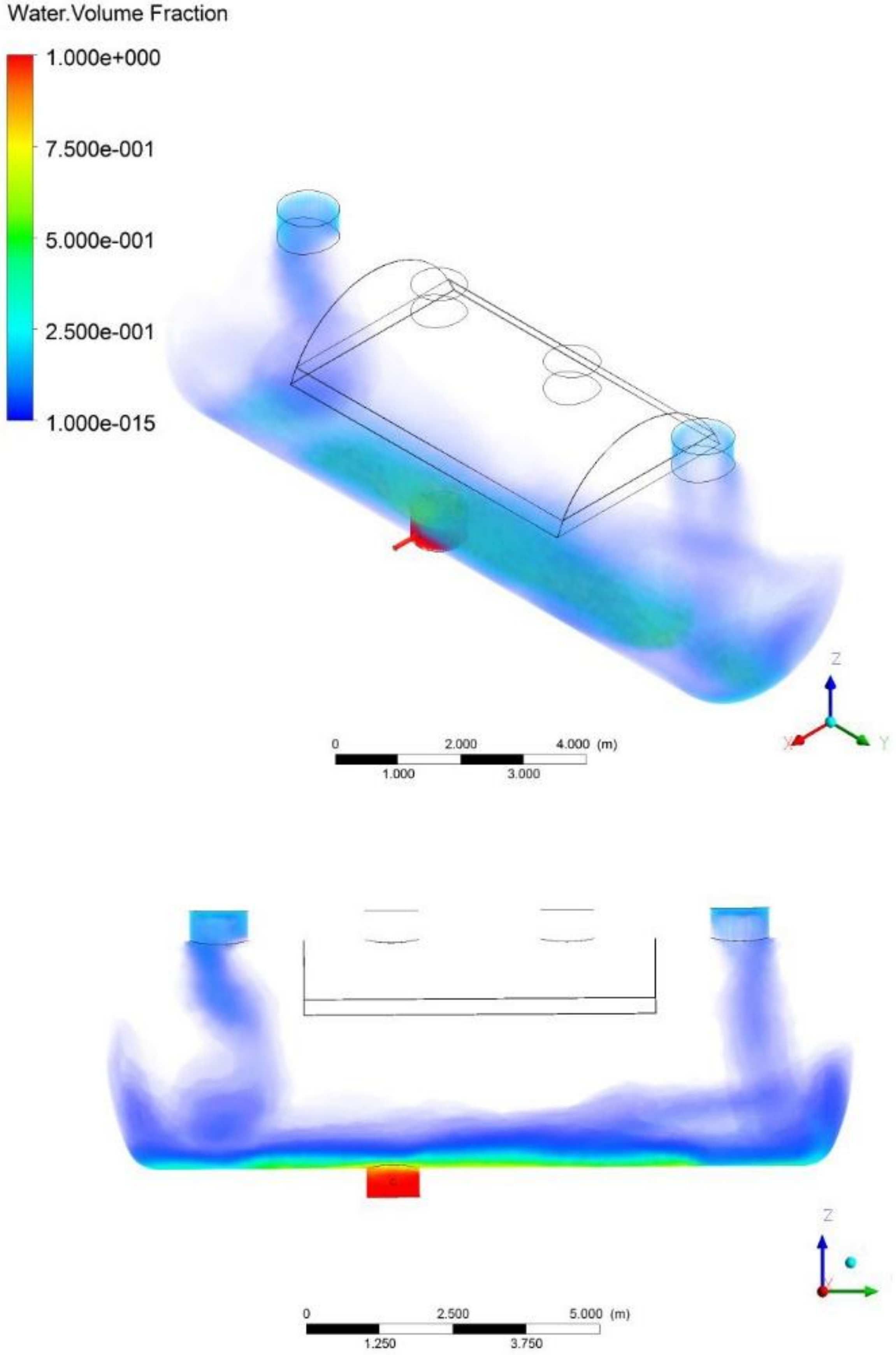


Figure 5: Water Volume Fraction at t=60 s

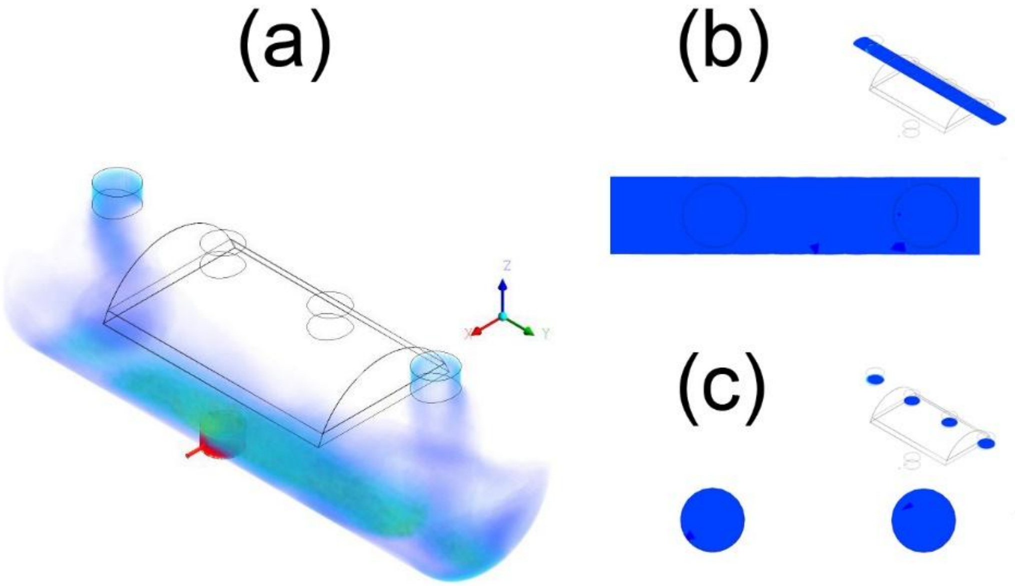


Figure 6: Water volume fraction at t=60 sec a) Isometric view of volume rendering b) level section at h=3820 mm c) level section at h=3940 mm

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