

Analysis of Liquid Fraction in Venturi Scrubber by E-E Method Using CFX

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Abstract: In this research, the distribution of liquid fraction in cylindrical venturi scrubber is analyzed in ANSYS CFX by Eulerian-Eulerian regime. Liquid gaps allow the aerosols to escape from the venturi scrubber. Therefore, it is vital to investigate the liquid fraction in venturi scrubber at different operating condition. The mesh model is developed in ANSYS ICEM and simulation is conducted in ANSYS CFX. $k-\epsilon$ turbulence model is used for simulation of two phase flow in venturi scrubber. The analysis is based on the boundary condition of mass flow rate for air inlet and static pressure for water inlet. For air mass flow rate 0.11, 0.14, 0.17 and 0.2 kg/s, respectively whereas static pressure 245 and 588 Pa for water inlet is used.

Keywords: Eulerian-eulerian, filtered vented containment system, liquid fraction, two phase flow, venturi scrubber,

INTRODUCTION

Filtered Vented Containment System (FVCS) has been suggested in case of severe accidents in Nuclear Power Plant (NPP) (Schechtman and Heising, 1996). FVCS protect the integrity of the system due to overpressure buildup inside the containment of NPP. It effectively removes the aerosols produced in the event of core melt down. This system is provided with venturi scrubbers through which contaminated gas is vented. The schematic diagram of FVCS is shown in Fig. 1. Venturi scrubbers collect these aerosols in petite droplets generated from scrubbing of water due to high kinetic of gas passing at throat. Venturi scrubber is prominent due to its duality removal function of aerosol i.e., capturing and absorbing. Venturi scrubber consists of mainly three nozzles: a convergent, a throat and a diffuser. These nozzles are connected in such a way that the gas first accelerate to its maximum velocity. In second nozzle, it attains the uniform velocity and finally decelerated in third nozzle. Venturi scrubber have either circular or rectangular cross-section. The scrubbing liquid is introduced in the way of high kinetic energy gas at convergent or throat section. The interaction of liquid is taken place in throat section. The advantages of venturi scrubber are; simple in design, occupies less space, operated at high temperature. On the other hand, the disadvantages are high operating cost and handling of effluents (Economopoulou and Harrison, 2007).

CFD has emerged as a power tool to improve the design and physical phenomenon in it. Liquid fraction

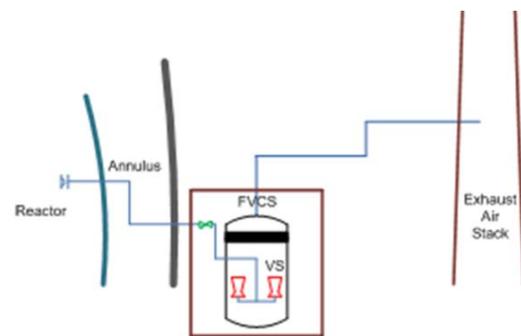


Fig. 1: Filtered vented containment system in nuclear power plant (Kolditz, 1995)

in venturi scrubber is a function of operating parameters such as the injection system and the fluid velocities.

The liquid-free areas permit the aerosols to flee from the venturi scrubber without any contact with the liquid. As a result, the removal efficiency of aerosols in venturi scrubber is decreased. The appropriate coverage of dispersed liquid in the throat strongly influences the removal efficiency of venturi scrubber (Lehner, 1998).

In this study, the liquid fraction is analyzed in venturi scrubber based on Eulerian-Eulerian approach with the help of ANSYS CFX to improve the design.

NUMERICAL METHODOLOGY

Turbulence model: The simulation of two phase flow in venturi scrubber is conducted by Euler-Euler



Fig. 2: Mesh of venturi scrubber generated in ANSYS ICEM

approach in steady state. In the domain, gas behave as continuous fluid whereas liquid as dispersed fluid. The two phase flow is simulated by using $k-\epsilon$ turbulence model for gas and dispersed phase zero equation model for liquid. For buoyancy calculations, the density difference ($\rho-\rho_{ref}$) is evaluated for buoyancy model (ANSYS, 2010).

Mesh: The domain of venturi scrubber model is discretized into 161252 hexahedral elements and 169808 nodes. The mesh quality of the venturi scrubber model is greater than 0.6 on the scale from 0 to 1 based on mesh quality criteria of ANSYS (2010) ICEM. A slice of mesh is shown in Fig. 2.

Solver: Upwind advection scheme is selected for accurate numerical solutions. It is used due to its robustness.

Convergence criteria: The convergence criterion chosen for all parameters is RMS residual $<10^{-5}$. The imbalance of liquid and gas is monitor to check the convergence of solution.

Boundary condition: The boundary conditions of venturi scrubber model are defined as follows: At the inlet, the mass flow rate of the gas is specified. The static pressure is applied at water inlet. The direction of the flow is defined normal to the boundary for mass flow inlet where zero gradient is used for pressure. At the outlet of venturi scrubber, the pressure boundary condition is applied. At all the walls, a no-slip boundary condition is imposed for both liquid and gas.

Grid independency: The grid independency plays a vital role for CFD simulation. Although it can increase the time of simulation with the mesh density, but it is very important to get the close results. For the selection of optimize mesh, three models of different mesh

density are selected. The number of mesh elements in these models are; 100056, 161252, 222480. These models are simulated at static pressure 245 Pa for water inlet and mass flow rate of gas at 0.08 kg/s. The results are found similar for 2nd and 3rd model. Therefore, the model containing 161252 mesh elements is selected for entire simulation.

Near wall treatment: The flow of fluid near to the wall is treated using scalable wall function. The yplus value lies within the range 30 to 300.

RESULTS AND DISCUSSION

When the contaminated gas passes through the throat of venturi scrubber develops the suction of liquid due to low pressure. The entered liquid is scrubbed into petite droplets due to the high kinetic energy of gas. These petite droplets distributed in the venturi scrubber depend on the turbulence of gas. The aerosol passing through the venturi scrubber hits the droplets and encapsulate in it. If the liquid is not found in certain areas, than probably these aerosols escape from the device. Therefore, it is important to study the liquid fraction in venturi scrubber operated at different condition. Venturi scrubber has two main operating variables: throat gas velocity and liquid fraction (liquid to gas ratio) (Ravi *et al.*, 2003). The removal efficiency of a venturi scrubber is enhanced with the increase of quantity of liquid to gas ratio and with the increase of gas velocity in the throat (Lehner, 1998). The liquid fraction determines the uniformity of liquid distribution inside the scrubber. The good distribution of liquid fraction increases the removal efficiency of venturi scrubber.

This study is conducted to locate the high and low region of liquid fraction simulated at different condition in venturi scrubber. Therefore, distribution of liquid fraction is analyzed in venturi scrubber as depicted in Fig. 3 and 4. The venturi scrubber is simulated with four different gas mass flow rate 0.11, 0.14, 0.17 and 0.2 kg/s, respectively and static pressure 245 and 588 Pa for liquid inlet is used. The model does not take into account the effect of film flow. It assumes drops of uniform size, no drop-drop interactions and breakup of droplets.

The contours at different static pressure for liquid inlet and mass flow rate for air inlet are shown in Fig. 3 and 4. The amount of liquid introduced into the scrubber depends on static pressure at liquid inlet. At higher static pressure, liquid flow rate is higher. But, the distribution of liquid depends on the turbulence of gas. It is observed that the liquid fraction is uniformly

Liquid inlet when static pressure = 245Pa

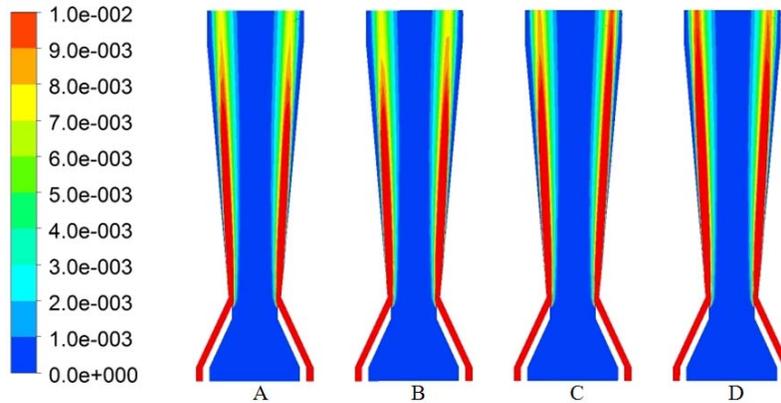


Fig. 3: Contours of boundary condition for liquid inlet when static pressure = 245 Pa and gas mass flow rate (A) 0.11 kg/s, (B) 0.14 kg/s, (C) 0.17 kg/s (D) 0.2 kg/s

Liquid inlet when static pressure = 588Pa

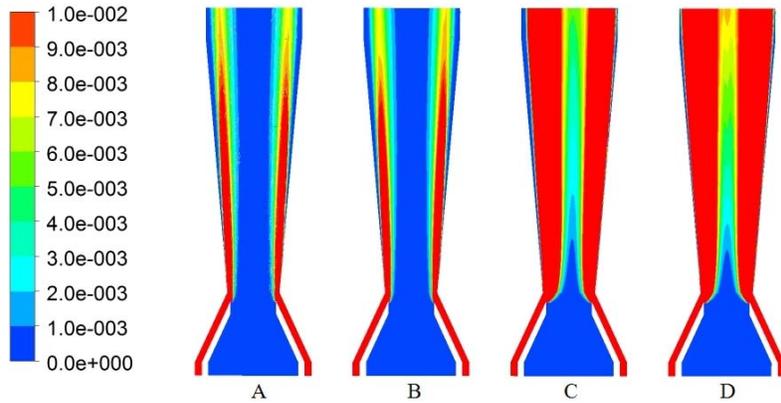


Fig. 4: Contours of boundary condition for liquid inlet when static pressure = 588 Pa and gas mass flow rate (A) 0.11 kg/s, (B) 0.14 kg/s, (C) 0.17 kg/s (D) 0.2 kg/s

distributed in radial direction. At static pressure 245 Pa, the distribution of liquid is almost similar for all mass flow rate. But, the effect of liquid fraction is quite significant in case of static pressure 588 Pa. The diameter of gas core region is higher at lower mass flow rate and it is decreased with the increase of gas mass flow rate. Mostly area of venturi scrubber is covered with liquid fraction at higher mass flow rate and static pressure. At higher mass flow rate, the pressure at throat is lower which cause more suction of liquid and higher turbulence cause the liquid distributed in the region.

CONCLUSION

k-ε turbulence model is used to analyzed the volume fraction in venturi scrubber. The gas turbulence affects the volume fraction in venturi scrubber. It is observed

that the diameter of gas region decreases with the increase of gas mass flow rate and static pressure at liquid inlet. The liquid is distributed uniformly in venturi scrubber in radial direction.

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