CFD Analysis for Eductor in Neutralization Pit of Wastewater

Project no. – EPM-11

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CHAPTER 1
Introduction

The given model i.e. neutralization pit has been developed to mitigate the Industrial waste water problem by controlling the pH value. To control the pH value of waste water, solution of NaOH (base) and HCl (acid) has been used and to achieve optimum mixing of in large compartment, three educators have been utilized. The wastewater from compartment A is circulated to compartment B and/ C till desired pH value. The numerical analysis has been carried out to find out the mixing characteristics in neutralization compartment (i.e. B/C). For the study following assumptions have been made:

i. The effect of internal components in the compartment on mixing is negligible and hence neglected.
ii. The flow from compartment B & C to A through penstock is due to the pressure gradient between two compartments.
iii. The relative amount NaOH and HCl is negligible and hence neglected.
iv. Two phase flow has been considered to understand the mixing phenomena. Compartment, i.e. Phase [I] wastewater in the compartment and Phase [II] wastewater flowing out from the eductor in the compartment.

The compartment B and C are geometrically identical; therefore, it is sufficient to perform numerical analysis for either of the compartment only with different pump cases. Figure 1. shows the geometry of given neutralization pit. To bound the problem to mixing characteristics only, it is desirable to consider steady state condition at given wastewater level. Also, it is sensible to consider the CFD model with the height of wastewater only as shown in Fig. 2. The (3X) eductor in each compartment is consist of nozzle followed by diffuser each (i.e. total number of eductors placed in B + C = 6). For the numerical analysis of the model three different cases has given as follows:

CASE No.	Total Flowrate delivered (gpm)	Differential Pressure delivered (psig)	No. of eductors working in the system	Flowrate per Eductor (gpm)	Wastewater level (m)
CASE [I]: **A to B only**	240	62.7	3	80	1.3
CASE [II]: **A to B + C**	240	62.56	6	40	1.4
CASE [III]: **A to B + C**	240	56.07	6	40	2.4

Table 1. CASE description

The compartment (B and C) is configuration (15 X 2.85 X 3.5) m^3. All eductors are placed 0.45 meter above from bottom of the compartment. However, the CFD model is developed according to the wastewater height, as per the given CASES.

The mixing characteristics in the tank is strongly coupled with the kinetic energy transformation by the eductor. Therefore, it is desirable to know the accurate flowrate from eductor. For the same the energy balance has been performed over the single eductor in next chapter.

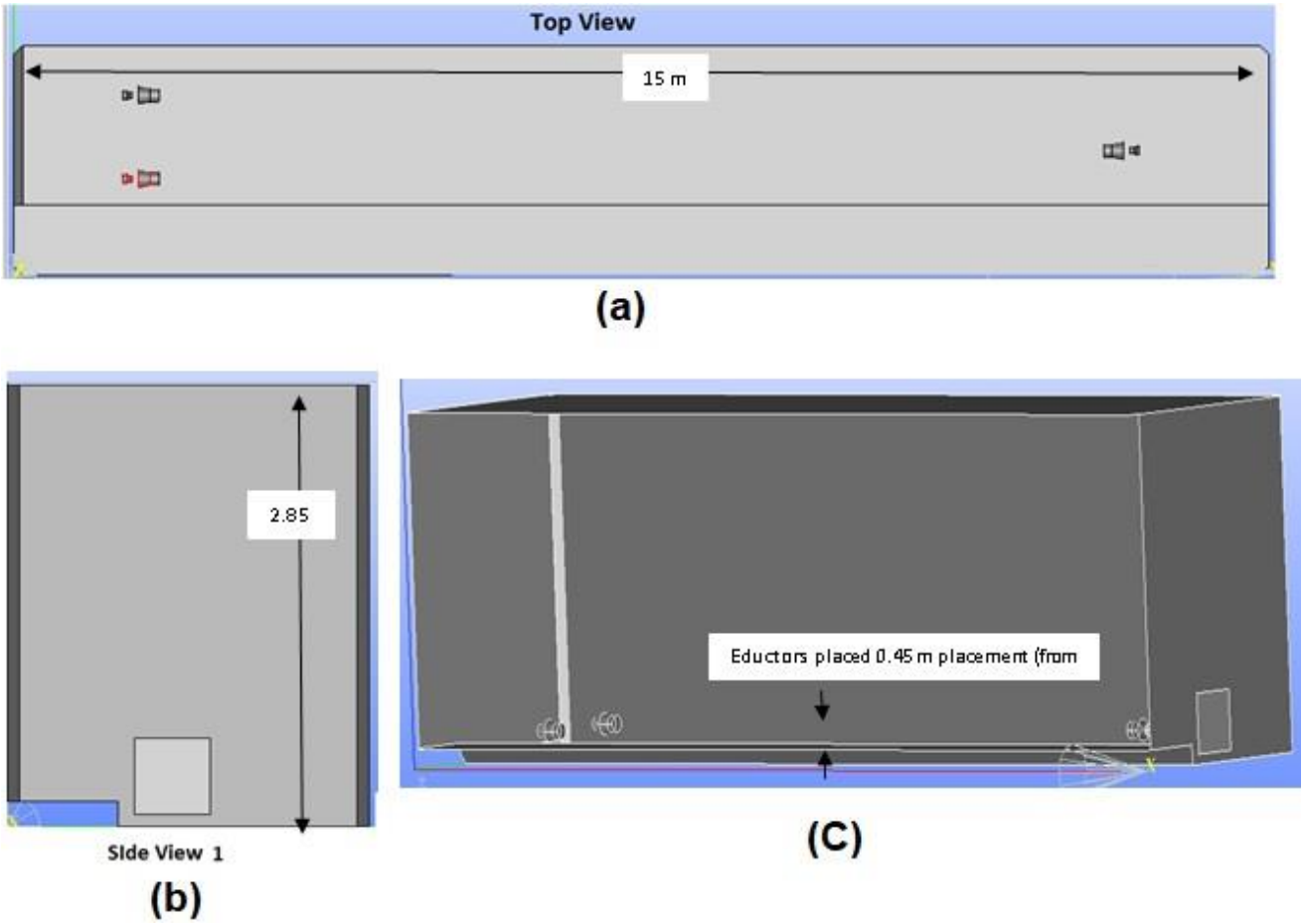
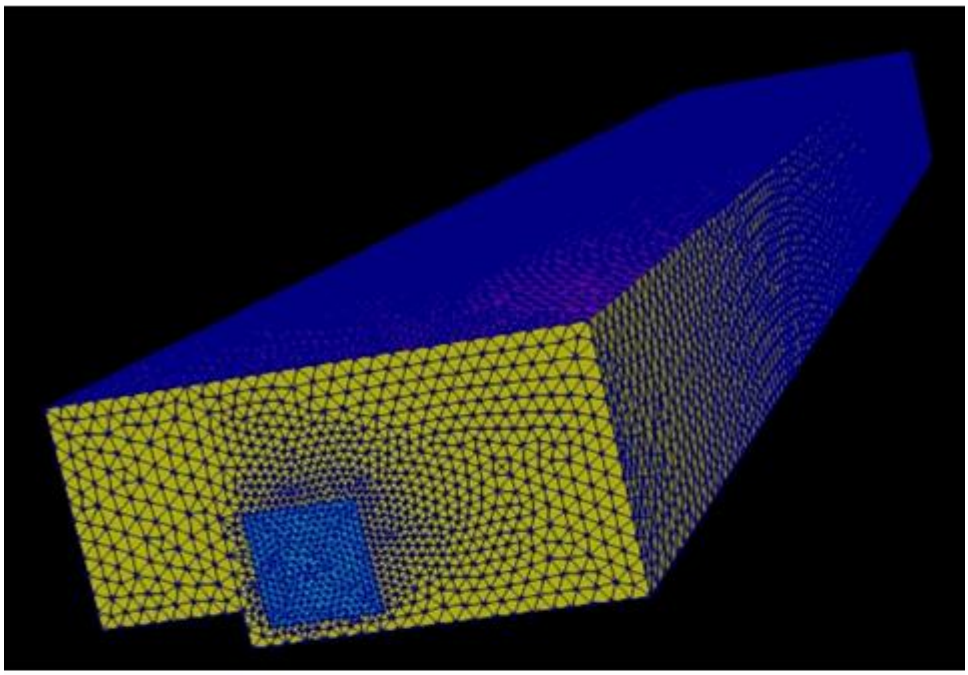
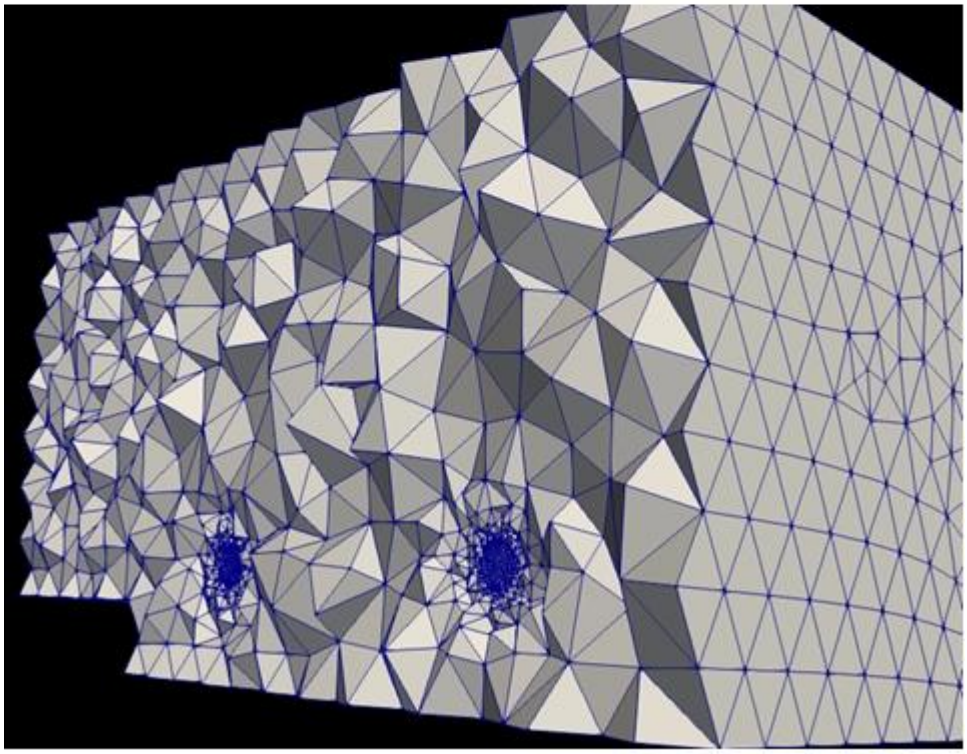


Figure 1. Geometry of neutralization pit i.e. Compartment B/C



(a)



(b)

Figure 2. CFD Model of Neutralization Pit

CHAPTER 2
Flowrate Calculations over Single Eductor

The mixing characteristics in the compartment is significantly depend on volumetric flowrate from the eductor. Therefore, it is wise to sense the actual volumetric flowrate from the eductor. For the same, the energy balance has been carried out for the given eductor design.

Figure 1. depicts the eductor design. Basically, the eductor consist of two subparts one is nozzle and second is diffuser. Motive fluid flows through the nozzle part. Here, all energy delivered by the pump will be converted into kinetic energy and then flow from nozzle will proceed towards diffuser. Due to profound design of the eductor, intensive kinetic energy produced by nozzle will drag the wastewater from the compartment into the diffuser. Therefore, here the flow delivered to the diffuser is summation of Motive Flowrate and Entrain Flowrate (dragged fluid from inside of the compartment). To predict the volumetric flowrate from the eductor the energy balance need to carry out over nozzle part first and the diffuser part as shown.

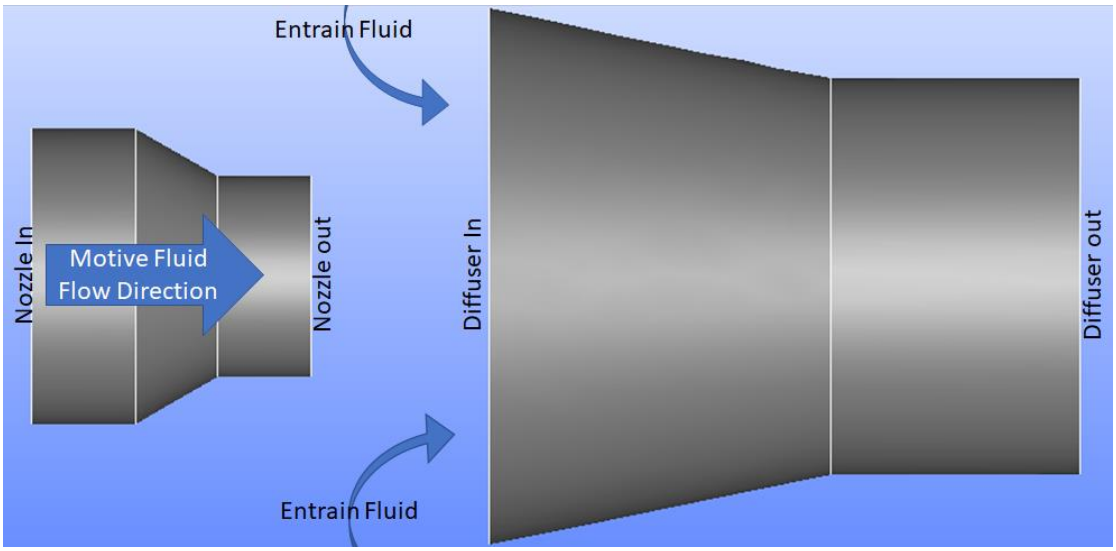


Figure 3. Eductor Design (neglecting joints)

To carry out energy balance following assumptions has been made.

[NOTE: IN CFD ANALYSIS, FOR THE SAKE OF ACCURATE BOUNDARY CONDITIONS, THE DIFFERENTIAL PRESSURE DELIVERED BY THE PUMP HAS BEEN CONVERTED TO KINETIC ENERGY]

Assumptions made:

i. Joints between nozzle part and diffuser part neglected (considerably doesn't affect on flow).
ii. The flow is potential flow.
iii. Eductor is at height 0.45 m from the bottom.

iv. Wastewater height is as shown in Table. 1.
v. All eductors are of same dimensions.

For CFD analysis the given parameters are as follows:

i. Surface Area of Nozzle Inlet S_{Nin} = 0.011433 m^2
ii. Surface Area of Nozzle Outlet S_{Nout} = 0.00525 m^2
iii. Surface Area of Diffuser Inlet S_{Din} = 0.037694 m^2
iv. Surface Area of Diffuser Outlet S_{Dout} = 0.020592 m^2
v. Volumetric Flowrate delivered by Pump $Q_{(kinematic\ head)}$ = 0.0151 m^3/s (240 USGPM)
vi. Entrain Flow Rate per eductor = 0.0202 m^3/s (320 USGPM)
vii. Pump Pressure Discharge = 468843 N/m^2 (68 psig)
viii. Wastewater Density ρ = 1042 Kg/m^3

Calculations:

Steps Performed:

[I] Hydrostatic Pressure at the outlet of each nozzle: (general for all eductors)
[II] Flowrate developed due to Differential Pressure at the Eductor (Converting Pressure to Kinetic Energy at the Nozzle)
[III] Flowrate Delivered due to Kinematic Energy by the pump at each Eductor
[IV] Total Flowrate out from each Nozzle
[V] Flowrate in to the diffuser

[I] Hydrostatic Pressure at the outlet of each nozzle: (general for all eductors)

All eductors are immersed at 0.85 m. below from the wastewater surface. Therefore, the pressure at the outlet of the nozzle is given by (P_2)

$$P_2 = (\text{density of wastewater}) \times (\text{gravitational acceleration}) \times \text{height}$$
$$P_2 = 1042 \times 9.81 \times 0.85$$

$$\mathbf{P_2 = 8688.717\ N/m^2} \qquad \textbf{(I.a)}$$

[II] Flowrate developed due to Differential Pressure at the Eductor (Converting Pressure to Kinetic Energy at the Nozzle)

$$\mathbf{Q_{(pressure\ head)} = C_d \times S_{Nout} \times [2 \times (P_2 - P_1) / \rho(1 - \beta^4)]}$$

β = Pipe Diameter / Nozzle Diameter
β = 0.12066 /0.08176
β = 1.47578, β^4 = 4.743364
C_d = Coefficient of Discharge, (0.98)

For CASE [I]

The pump pressure discharge is of 468843 N/m^2 (68 psig). Neglecting losses, the pressure at the nozzle inlet is (P_1) 432301.3 N/m^2 (62.7 psig). The flow rate developed due to differential pressure $Q_{(pressure\ head)}$ is given by

$$Q_{(pressure\ head)} = 1.1751\ m^3/s \qquad \text{(II.a)}$$

For CASE [II]

The pump pressure discharge is of 468843 N/m^2 (68 psig). Neglecting losses, the pressure at the nozzle inlet is (P_1) 431336.016 N/m^2 (62.56 psig). The flow rate developed due to differential pressure $Q_{(pressure\ head)}$ is given by

$$Q_{(pressure\ head)} = 1.11496\ m^3/s \qquad \text{(II.b)}$$

For CASE [III]

The pump pressure discharge is of 468843 N/m^2 (68 psig). Neglecting losses, the pressure at the nozzle inlet is (P_1) 386589.04 N/m^2 (56.07 psig). The flow rate developed due to differential pressure $Q_{(pressure\ head)}$ is given by

$$Q_{(pressure\ head)} = 0.99691\ m^3/s \qquad \text{(II.c)}$$

[III] Flowrate Delivered due to Kinematic Energy by the pump at each Eductor:

[NOTE: IN CASE [I]: 3 EDUCTORS ARE WORKING ONLY, IN CASE [II] AND [III] 6 EDUCTORS ARE WORKING, ACCORDINGLY 240 GPM WILL BE DIVIDED IN EACH EDUCTOR]

For CASE [I]

In CASE [I], the total flowrate is given as 0.01515 m^3/s (240 USGPM) and wastewater is flowing only from compartment A to B, i.e. 3 eductors are working only. Therefore, flowrate per eductor is: 0.00505 m^3/s (80 USGPM)

$$Q_{(pressure\ head)} = 0.00505\ m^3/s \qquad \text{(III.a)}$$

For CASE [II]

In CASE [II], the total flowrate is given as 0.01515 m^3/s (240 USGPM) and wastewater is flowing from compartment A to B and A to C as well, i.e. 6 eductors are working only. Therefore, flowrate per eductor is:

$$Q_{(pressure\ head)} = 0.002525\ m^3/s \qquad \text{(III.b)}$$

CASE [II]

In CASE [III], the total flowrate is given as 0.01515 m^3/s (240 USGPM) and wastewater is flowing from compartment A to B and A to C as well, i.e. 6 eductors are working only. Therefore, flowrate per eductor is: 0.00505 m^3/s (80 USGPM)

$$Q_{(pressure\ head)} = 0.002525\ m^3/s \qquad \text{(III.c)}$$

[IV] Total Flowrate out from each Nozzle:

The total nozzle flowrate out from each nozzle is the summation of flowrate delivered due to pressure head and kinematic head:

$$Q_{(total\ Nozzle\ Out)} = Q_{(pressure\ Head)} + Q_{(Kinematic\ Head)}$$

$$Q_{(total\ Nozzle\ Out)} = \text{(II.i)} + \text{(III.i)}$$

i = a, b, c

CASE [I] $Q_{(total\ Nozzle\ Out)} = 1.18015\ m^3/s$ **(IV.a)**

CASE [II] $Q_{(total\ Nozzle\ Out)} = 1.117485\ m^3/s$ **(IV.b)**

CASE [III] $Q_{(total\ Nozzle\ Out)} = 0.999435\ m^3/s$ **(IV.c)**

[V] Flowrate in to the diffuser:

[ENTRAIN FLOWRATE IS SAME IN ALL CASES, i.e. 0.0202 m^3/s (320 USGPM)]

$$Q_{(DiffuserIn)} = Q_{(total\ flowrate\ out\ from\ nozzle)} + Q_{(Entrain\ fluid\ flow)}$$

$$Q_{(DiffuserIn)} = \text{(IV.i)} + 0.0202$$

CASE [I] $Q_{(DiffuserIn)} = 1.20035\ m^3/s$ **(V.a)**

CASE [II] $Q_{(DiffuserIn)} = 1.137685\ m^3/s$ **(V.b)**

CASE [III] $Q_{(DiffuserIn)} = 1.019635\ m^3/s$ **(V.c)**

[VI] Flowrate out from the diffuser:

Applying Bernoulli's Principal over diffuser:

$$Q_{(DiffuserOut)} = Q_{(DiffuserIn)}$$

$$S_{Dout} \times V_{Dout} = S_{Din} \times V_{Din}$$

$$V_{Dout} = (S_{Din} \times V_{Din}) / S_{Dout}$$

CASE [I] V_{Dout} = 58.29055 m/s

CASE [II] V_{Dout} = 55.24889 m/s

CASE [III] V_{Dout} = 49.51607m/s

Also, volumetric flow rate is given by:

CASE [I] Q_{Dout} = 1.20031 m/s (VI.a)

CASE [II] Q_{Dout} = 1.13768 m/s (VI.b)

CASE [III] Q_{Dout} = 1.01963 m/s (VI.c)

CHAPTER 3
Numerical Model, Operating Conditions & Boundary Conditions

Figure 2. depicts the generated grid used for the analysis. Using multiphase flow Volume of Fluid method. For turbulence modelling k-Omega SST model has been applied as it showed improved performance for the current study. Also, the turbulence intensity is assumed to be 3% (medium turbulence) and turbulence properties calculated based inlet velocity. The thermos-physical fluid properties and the initial and boundary conditions applied has shown in Table 2 and 3 respectively. To satisfy the continuity equation and to achieve realistic flow conditions, the top surface of CFD model has considered to be at atmospheric boundary condition. The initial internal field has kept 0 for velocity and pressure.

Fluid Property/Fluid Phase	Wastewater in the tank (phase 1)	Wastewater in the tank (phase 2)
Kinematic viscosity (m2/s)	1e-6	1e-6
Density (kg/m3)	1042	1042

Table 2. Thermophysical Properties of fluid

Parameters/Boundary type	**Walls**	**Eductor outlet**	**top**	**Compartment outlet**	**Internal Field (Initially)**
Velocity (m/s)	noSlip	Volumetric flow rate (m^3/s)	Atmospheric	Pressure outlet	Uniform 0
Pressure (N/m2)	Fixed flux pressure	Fixed flux pressure	Uniform 0 (atmospheric)	Fixed flux pressure	zeroGradient
New wastewater volume fraction	Zero gradient	1	Zero gradient	Zero gradient	0 (i.e. filled with old wastewater)
k (turbulence property) (m2/s2)	Wall function	3% (medium turbulence)	3% (medium turbulence)	3% (medium turbulence)	(calculated from velocity)
Omega (turbulence property) (1/s)	Same as Internal field	Same as Internal field	Same as Internal field	Same as Internal field	(calculated from velocity)

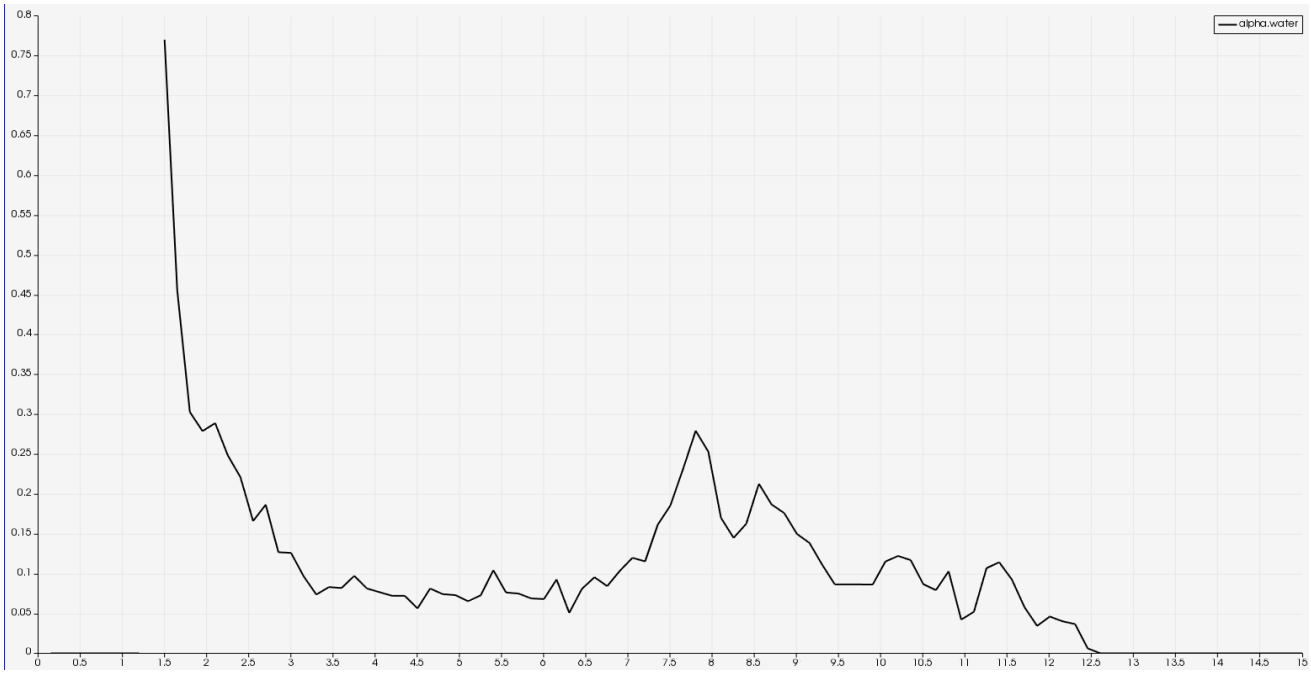
Table 3. Initial & Boundary Conditions

Chapter 3
Results and Discussion

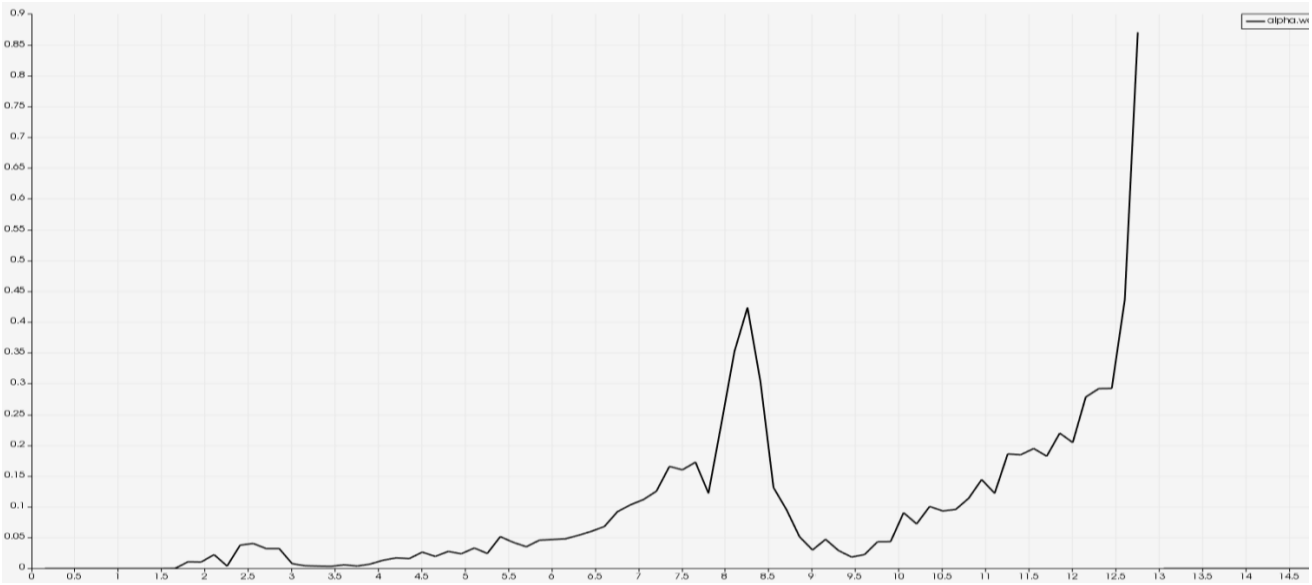
The study has been carried out for all three CASES. To find out the mixing characteristics in neutralization compartment, two phase model has been utilized i.e. wastewater in tank 1 is phase 1 and wastewater coming in the tank as phase 2. Therefore, the volume fraction of two phases in the compartment provides the mixing characteristics very well. In-detailed results and discussion has given in this chapter for all three CASES.

CASE [I]

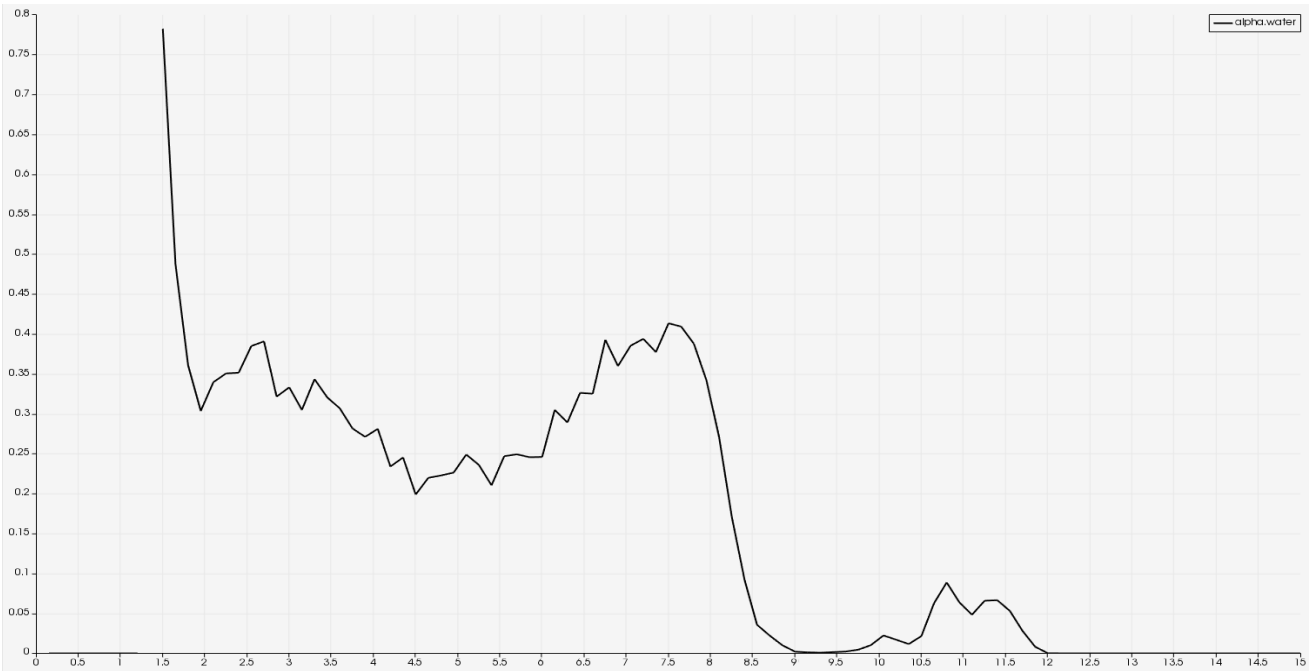
For CASE [I], the compartment is filled with wastewater till 1.3 m. height and the flow is only in between compartment A and B/C, i.e. only three eductors are working. To find out the mixing characteristics in neutralization compartment, two phase model has been utilized i.e. wastewater in tank 1 is phase 1 and wastewater coming in the tank as phase 2. Therefore, the volume fraction of two phases in the compartment provides the mixing characteristics very well. Figure 4 provides wastewater volume fraction (from eductor) over the line passing from the center of the eductor respectively at time 1200 secs. From Figure 4. it has been seen that the three eductors have provided the enough kinetic energy for mixing. Each eductor shows the capacity to drive the fluid over the length in the range of 10 to 11 meter in the compartment. The new incoming wastewater fraction found to be in the range of 0.35 to 0.5 in middle section of the compartment, which conforms the strong momentum force acting in this section. It might be due to the eductors opposite facing positions. However, due to the given position, the linear momentum energy transfer



(a) Line co-ordinates (0 1.25 0.45) to (15 1.25 0.45) passing from center of 1st eductor



(b) Line co-ordinates (0 2.25 0.45) to (15 2.25 0.45) passing from center of 2nd eductor



(c) Line co-ordinates (0 2.25 0.45) to (15 2.25 0.45) passing from center of 2nd eductor

Figure 4. wastewater fraction over the length of mentioned line co-ordinates passing from the center of the eductor at time t = 1200 secs

is dominant and therefore strong mixing has been observed only in the middle section of the compartment. At the corners and at the back of all three eductors, negligible momentum transfer has been observed (i.e. zero new wastewater fraction). Figure. 5. depicts the wastewater fraction over the horizontal section at the height interval of H = 0.1 meter (from bottom to top) at time t = 1200 secs. Figure 5. also, supports the statements concluded from Figure 4. in border way.

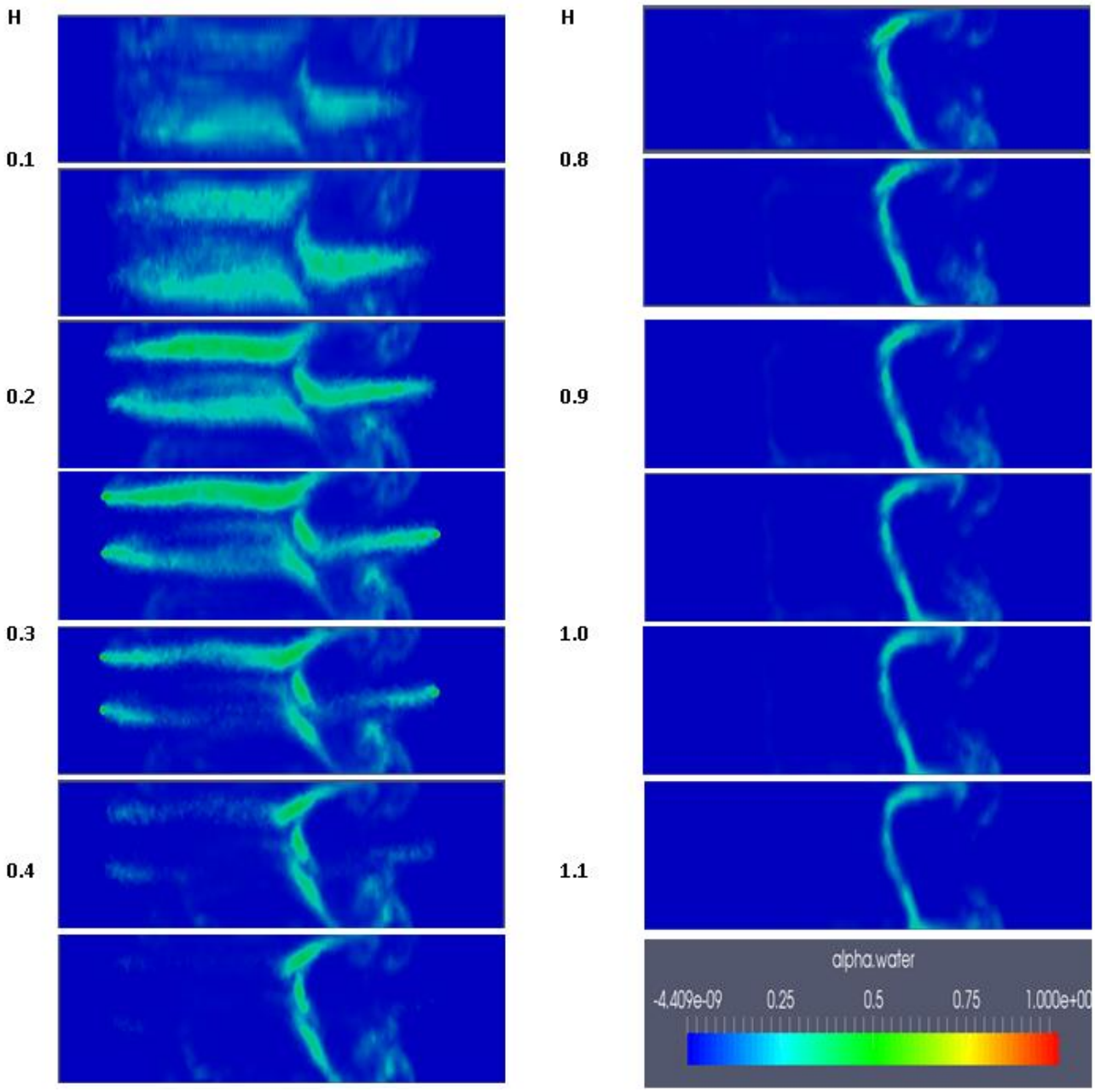
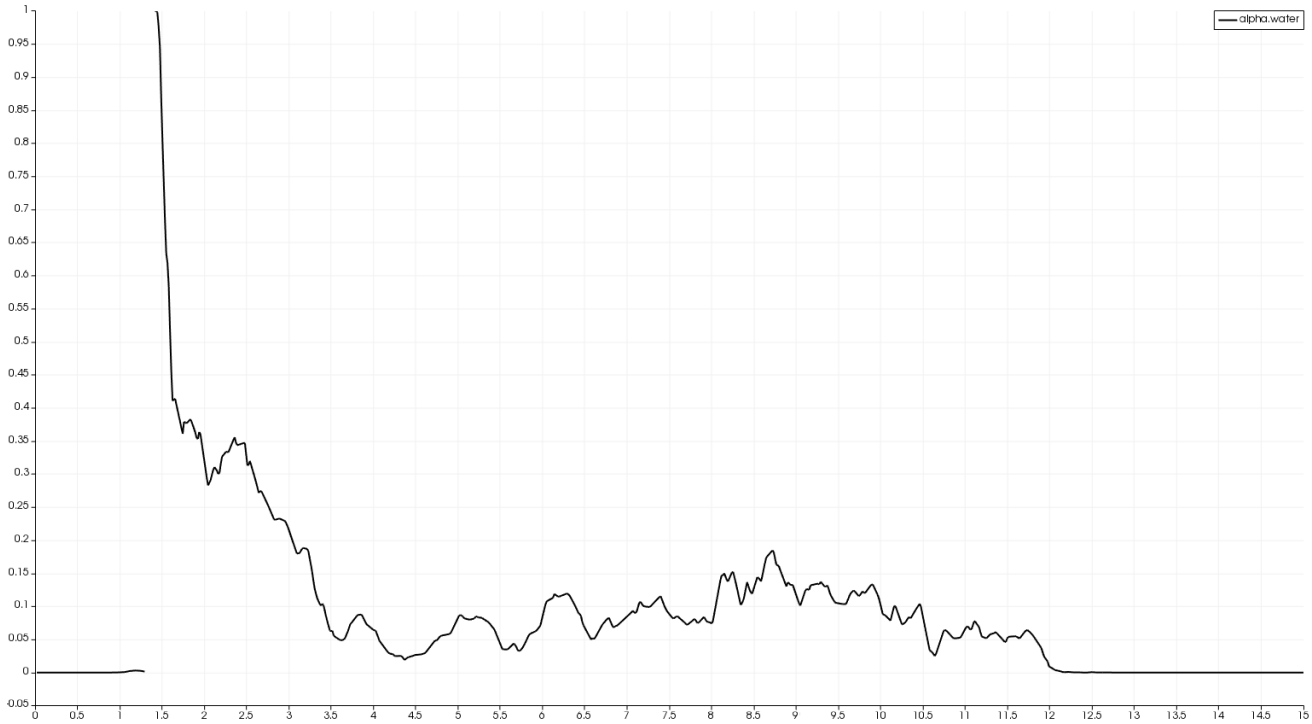


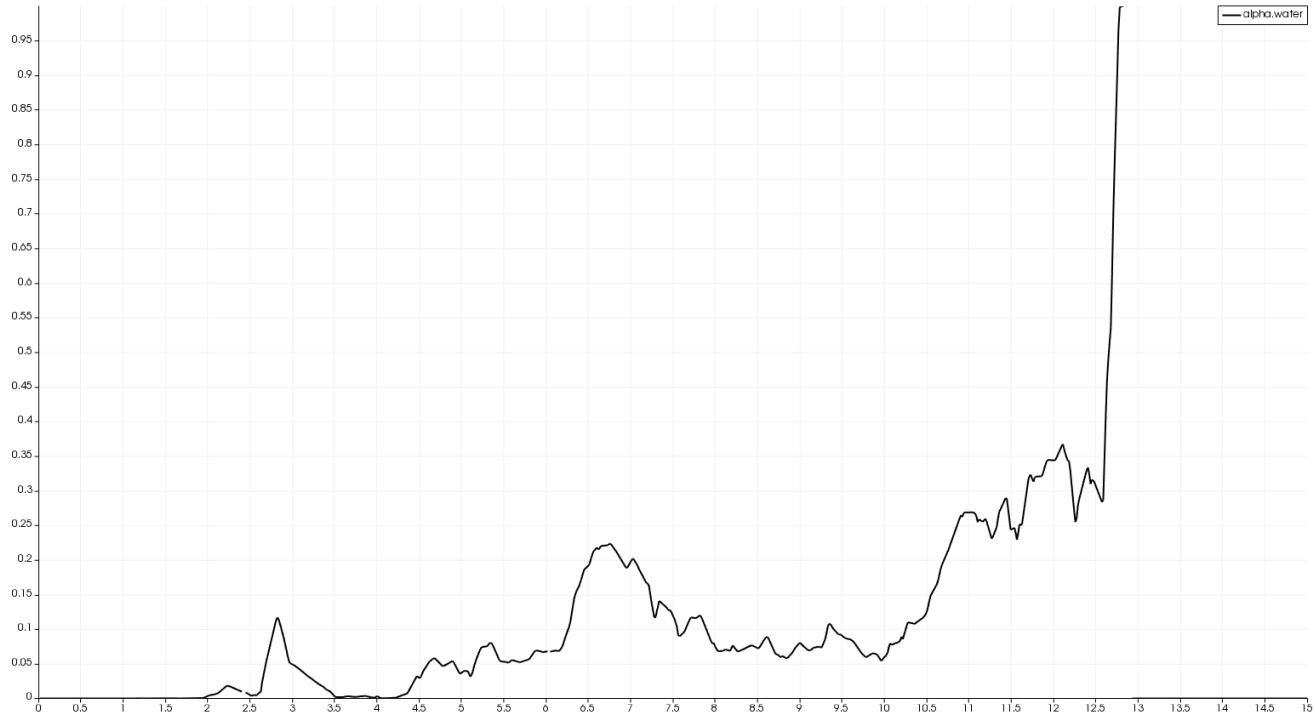
Figure 5. Wastewater fraction over the horizontal section at the height interval of H = 0.1 m (from bottom to top) at time t = 1200 secs (NOTE: alpha.water = new wastewater coming in the compartment from eductor) R = Range of wastewater fraction

CASE [II]

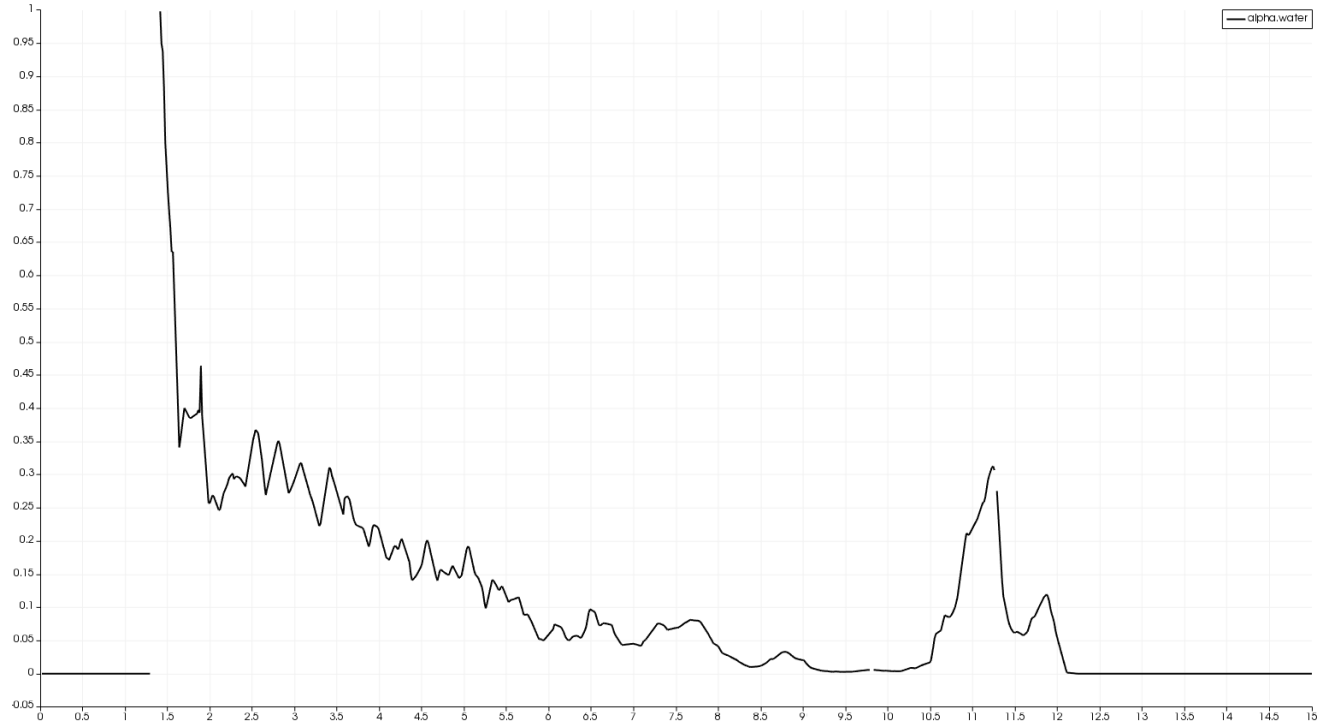
For CASE [II], the compartment is filled with wastewater till 1.4 m. height and the flow is in between compartment A and B+C, i.e. all six eductors are working. The wastewater fraction is similar to the CASE I throughout the compartment. Here also stagnation zone has been observed at both ends of the compartment at back of the eductor. Figure 6. depicts the wastewater fraction over the horizontal section at the height interval of H = 0.1 meter (from bottom to top) at time t = 1200 secs.



(a) Line co-ordinates (0 1.25 0.45) to (15 1.25 0.45) passing from center of 1st eductor



(b) Line co-ordinates (0 2.25 0.45) to (15 2.25 0.45) passing from center of 2nd eductor



(c) Line co-ordinates (0 2.25 0.45) to (15 2.25 0.45) passing from center of 3rd eductor

Figure 6. Wastewater volume fraction (from eductor) over the line passing from the center of the eductor respectively at time 1200 secs for mentioned locations

CASE [III]

For CASE [III], the compartment is filled with wastewater till 2.4 m. height and the flow is in between compartment A and B+C, i.e. all six eductors are working. The wastewater fraction is shown in Figure 7. At different horizontal cross-sections. Here also stagnation zone has been observed at both ends of the compartment at back of the eductor. Figure 7. depicts the wastewater fraction over the horizontal section at the height interval of H = 0.1 meter (from bottom to top) at time t = 1200 secs. Figure 8. depicts the wastewater fraction over the horizontal section at the height interval of H = 0.1 meter (from bottom to top) at time t = 1200 secs.

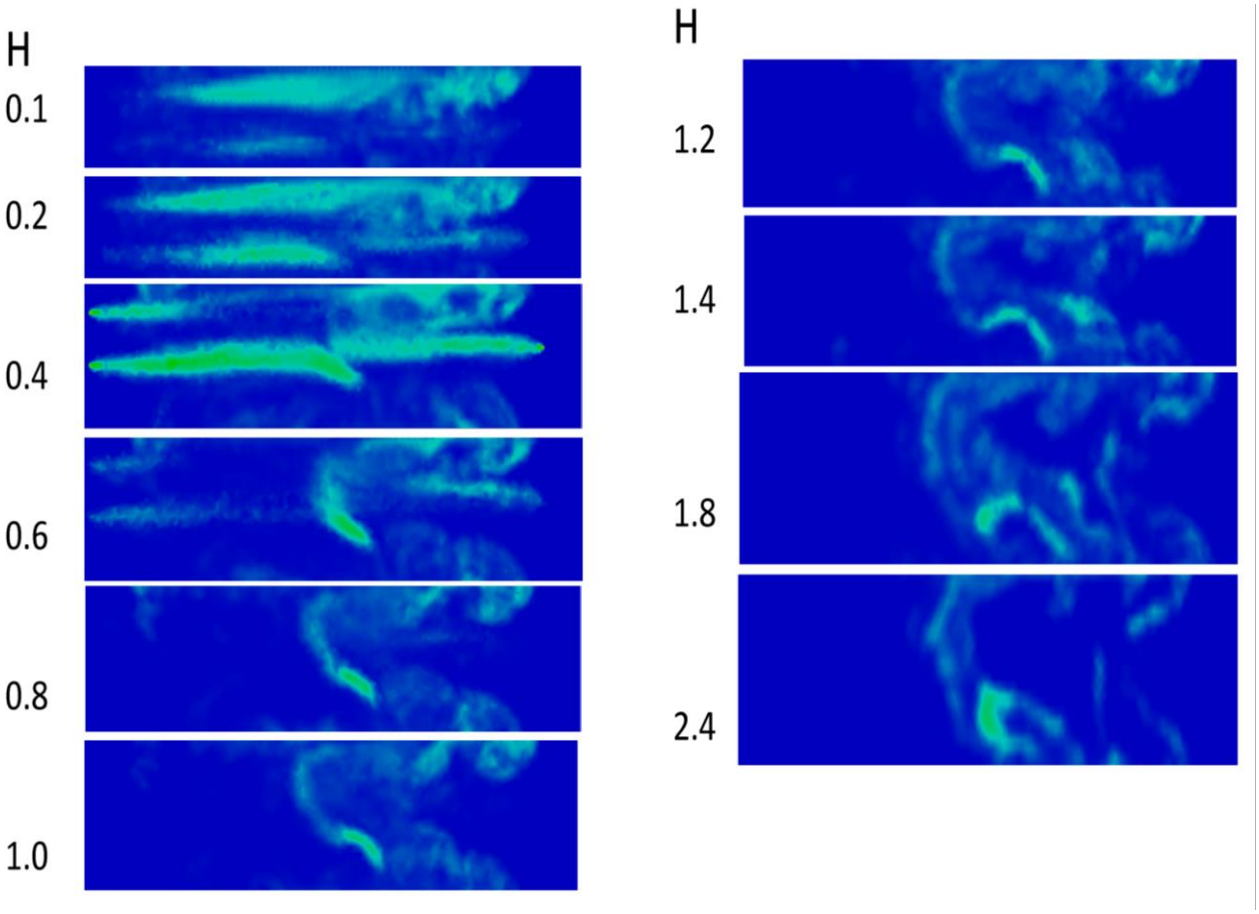
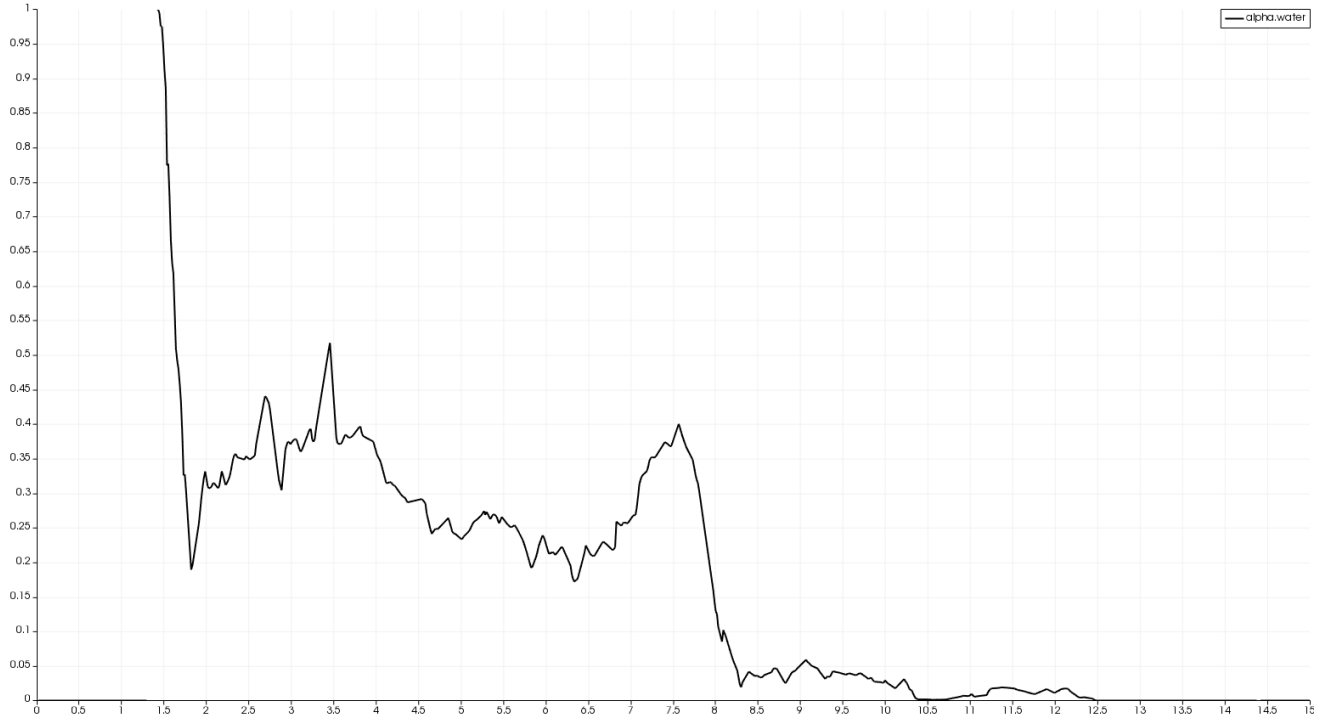
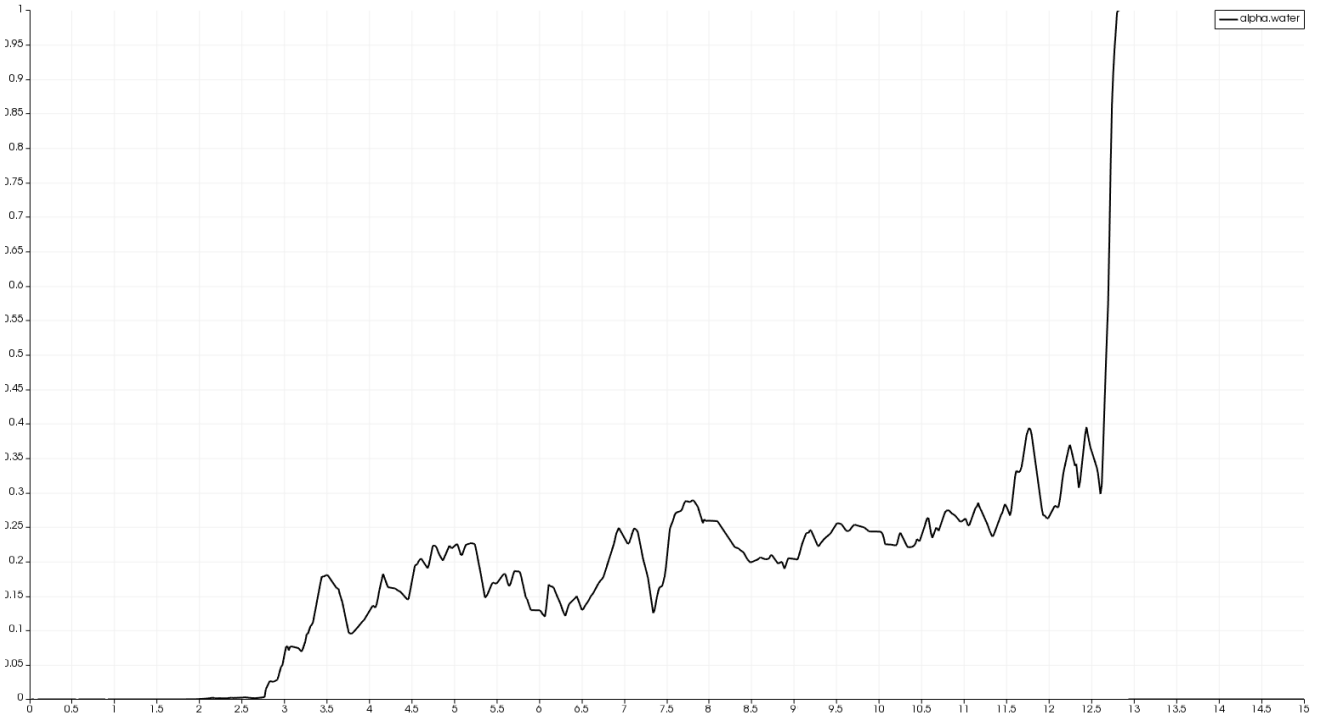


Figure 7. Wastewater fraction over the horizontal section at the height interval of H = 0.1 m (from bottom to top) at time t = 1200 secs (NOTE: alpha.water = new wastewater coming in the compartment from eductor) R = Range of wastewater fraction as mentioned in CASE I



(a) Line co-ordinates (0 1.25 0.45) to (15 1.25 0.45) passing from center of 1st eductor



(b) Line co-ordinates (0 1.6 0.45) to (15 1.6 0.45) passing from center of 2nd eductor

(c) Line co-ordinates (0 2.25 0.45) to (15 2.25 0.45) passing from center of 3rd educator

Figure. 8. Wastewater volume fraction (from eductor) over the line passing from the center of the eductor respectively at time 1200 secs with mentioned locations

From all studied CASES, it has been observed that with the provided energy (pressure + kinetic) by the pump, all eductors can provide enough energy transformation into Kinematic to given range of 10 to 11.5-meter length for momentum transformation. Due to the given position of the three eductors in the compartment, the momentum transfers vigorously in linear plane (i.e. in a line of eductor outlet) first and then at the center of the compartment due to the jet interaction it become more turbulent which supports mixing as well. However, from above all Figures, it has been found that in all CASES, the mixing is not significant at the back of the all eductors and also at the top and bottom plane comparatively.

CHAPTER 4
Conclusion

The numerical analysis has been carried out for all three CASES for 1200 secs. From Results & Discussion following conclusions have been extracted:

i. It can be concluded that, calculated flow rate has sufficient potential to deliver the required momentum for mixing.

ii. The given vertical position (i.e. 0.45 m.) of all eductors is sufficient to provide the momentum transfer to bottom of the compartment in all CASES. However, at the top after 1-meter height the momentum transfer starts weakening.

iii. From given eductor positions, there is only linear momentum transfer has occurred and therefore it only provides strong linear momentum i.e. linear mixing. The mixing has not been taking place throughout the compartment, specially at the corners. Stagnation zones have been observed at each corner as well as at the back of the eductors.

iv. To counter the stagnation occurred from given eductor positions, it is desirable to change the horizontal position.

v. Also, it would be more effective to consider the actual flowrate instead of calculated from the eductor, which plays a vital role for mixing in the compartment.

vi. It is also, desirable to increase the vertical position of one or two eductors in order to have uniform mixing at the top of the compartment.

CHAPTER 5
Suggestions & Future Scope

From the study, only linear mixing has been observed and hence study need to extend to enhance mixing in the compartment based on studied parameters. From the current analysis, following study have been proposed for future:

i. The liquid mixer is ideal benchmark to optimize the mixing in the compartment. The utilization of all three eductors should produce mixer type effect i.e. high turbulence with simultaneous vortex formation-deformation fluid structure in the compartment. This could be possible with different eductor angles and positions.

ii. The use of baffles at optimized location in the compartment also could lead to enhance the mixing in the compartment.

iii. Effect of different flowrate (i.e. varying kinematic and pressure energy) on mixing length of the eductor.

Based on above study, the eductor performance can be optimized and therefore, the number of eductors in the compartment also can be decided. Also, it would be needed to perform the experimental verification of the numerical analysis results carried out in this study.