Model Development of Settling Tank for Industrial Waste Water Treatment Plant

Project Report

Submitted in partial fulfillment of the requirements
for the degree of

MASTER OF TECHNOLOGY

IN

INSTRUMENTATION AND CONTROL ENGINEERING

(Control and Automation)

By

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MAY 2015

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Under the Guidance of

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MAY 2015

Declaration

This is to certify that

1. The Thesis comprises my original work towards the degree of Master of Technology in Instrumentation & Control Engineering at Nirma University and has not been submitted elsewhere for a Degree.
2. Due acknowledgment has been made in the text to all other material used.

NEEL PATEL
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Undertaking for Originality of the Work

I, **NEEL PATEL**, Roll.No.**13MICC28**, give undertaking that the Major Project entitled **Model Development of Settling Tank for Industrial Waste Water Treatment Plant** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Instrumentation and Control Engineering (Control and Automation) of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

Signature of Student

Date :
Place : NU, Ahmedabad

Endorsed by

Signature of Guide

Certificate

This is to certify that the Major Project entitled **Model Development of Settling Tank for Industrial Waste Water Treatment Plant** submitted by **NEEL PATEL (13MICC28)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Instrumentation and Control Engineering (Control and Automation) of Nirma University, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion the submitted work has reached a level required for being accepted for examination. The results embodied in this major project to the best of my knowledge haven't been submitted to any other university or institution for award of any degree or diploma.

Date : Place : Ahmedabad

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I am very much thankful to “The Green Environment services Co-op. Soc. Ltd.” and “Chemical Engineering Department, Nirma University” for providing support to carry out experiments.

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- NEEL PATEL

13MICC28

Abstract

Water treatment plants are designed on a unit operation concept in which one unit is optimized to accomplished one task. Modeling and simulation of water treatment processes have gained increasingly attention within past years. In particular, standardized mathematical models are implemented on the simulation environment and used for process equipment design, efficient and optimized operational controls and further research for different processes.

In this work, a mathematical modeling of sedimentation process in a typical waste water treatment plant has been developed and simulated using Matlab-Simulink framework. The model used to carry out a systematic study to understand the process behavior, and to investigate the effect of changes in various relevant process variables and parameters on the process performance.The results obtained with the proposed model are presented and a comparison is made between the distributed source model and model that includes only one layer in the feed zone. Also, for validation of the model ”Common effluent treatment plant-VATVA” site has been selected. For validation purpose required changes has been applied to develop model.

Nomenclature

Q_f	Inlet flow to sediment tank, m^3/hr
C_f	Solid's concentration in influent, kg/m^3
Q_e	Effluent flow, m^3/hr
C_e	Solid's concentration in effluent, kg/m^3
Q_r	Return flow to sediment tank, m^3/hr
C_r	Solid's concentration in sludge, kg/m^3
A	Cross sectional area of tank, m^2
D	Diameter of particles, μm
C_i	Solid's concentration of i^{th} layer
V_S	Settling velocity, m/hr
R	Specific gravity (1.65 for quartz in water)
g	Gravitational constant
V	Viscosity of water

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Chapter 1

Introduction

Wastewater treatment is process of removing impurities from water before employed for industrial, agricultural, or municipal uses. The techniques used to remove the impurities in wastewater can be divided into biological, chemical, physical and energetic. Different different techniques applied as the water passes through the stages. Primary treatment typically the removal of large solids from the wastewater via settling or filtration. The first step in waste water is screening. Secondary treatment usually removes the minor solids and particles remaining in the wastewater through filtration. Energetic techniques may also be employed in tandem with biological techniques in the secondary phase to break up the size of particles and increasing their surface area of particle and rate of consumption by the bacteria present. A first step in the secondary treatment process is to send the waste to an aeration tank. Tertiary treatment includes the disinfection of the wastewater by use of chemical or energetic means. With increasing in the steps apply to waste water may increases the quality of water. But as the more technologies applied to waste water it increases costs of operation and maintenance.

1.1 Operations of WTP

Below diagram represents the different operations of water treatment plant.

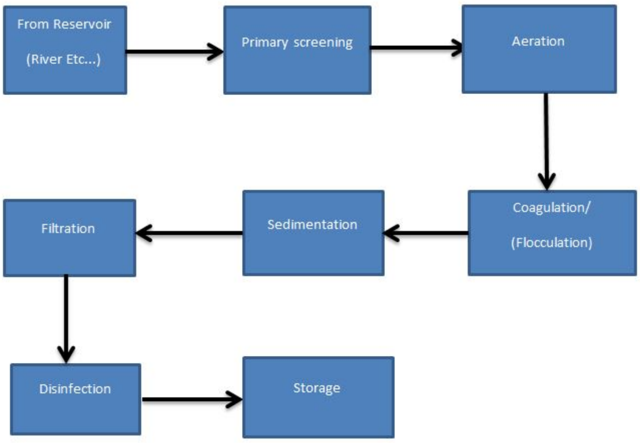

Figure 1.1: Operation of water treatment plant

The choice of treatment process used depends on the quality and variability of the raw water source and the treatment objective, which may vary with industrial to municipal needs.

1.2 Preliminary Screening

The raw water is firstly screened through a set of coarse screens (100mm spacing) to remove gross solids, such as litter and branches, before being conveyed to the plant. Prior to treatment it is screened again through fine screens or, if considerable fine solids or algae are present, then micro-straining maybe used before the next stage.

1.3 Aeration

Aerators expose water to the air to remove volatile dissolved components that are in excess of their saturation concentration. Some of the toxic organics are volatile. Compounds like Fe and Mn, can be removed to satisfactory levels as it may causes odor and taste. Adding of dissolved oxygen improves the oxidation of iron, manganese, and other metals to higher and more soluble oxidation. Aeration also reduce the corrosiveness of the water by driving CO2 and raising the pH. However, aeration alone cannot reduce the corrosive properties of acid water; neutralization using lime may also be needed. Aeration is one of the first treatment operations applied to water.

1.4 Flocculation

One of the first steps in a water purification process is the adding of chemicals to support in the removal of suspended solids in water. Particles can be inorganic or organic, such as clay, silt algae, bacteria, viruses, protozoa and natural organic matter. Inorganic and organic particles contribute to the turbidity and color of water. Flocculators offer mild agitation of water that has been coagulated to promote particles contact and creation of larger particles.

1.5 Sedimentation

Waters from the focculator then enters the sedimentation tank, also referred as a clarifier or settling tank. It consist of a large tank with low water velocities, permitting floc to settle to the bottom of the tank. The sedimentation tank is finest if located close to the flocculator so the transport between the two processes does not permit settlement of solids in between. Sedimentation tank may be rectangular, where water flows from end to end or circular where flow comes from the center of tank and then clear water available at top of tank. In this process clear water is available at the top of the tank and sludge removed from bottom of the tank.

1.6 Filtration

After sedimentation filtration is applied to water. Filtration completes polishing of water. Very small particles that did not settle in sedimentation tank will be removed with filtration process. It also removes bacteria in a filter but not enough significant to provide a safe water. Larger microorganisms such as protozoans are completely removed in a properly operated filter.

Two types of filtration available at the common use of waste water treatment. Only sand media in slow sand filtration. It can be easily cleaned by changing the top layer of media on a periodic basis as the filter clogs. Rapid filters are sand filters or multimedia filters that have anthracite, sand, and possibility other media in them. Loading rates of rapid filters are much higher than slow sand filters. Rapid filters are cleaned by backwashing -reversing the flow of the water through the media and pumping at a rate sufficient to expand the media.

In smaller installations pressure filters are used, in which water is forced through the filter by applied pressure in a completely closed unit. Roughing filters that contain coarse media may be used to pre-filter water with very high suspended solids content. Raw water that is of high quality may require filtration only to remove the small quantities of suspended solids that are present.

1.7 Disinfection

Disinfection is the removal of bacteria or microorganisms. Chemical agents may be used or the water maybe exposed ultraviolet (UV) light or radiation. Ozone is becoming more widely used as a disinfectant. The disinfection tank or device (such as a UV chamber) maintains the water in contact with the dose of disinfectant for a time long enough to ensure the required log reductions in indicator bacteria. It is exceedingly rare to find raw water that would not require disinfection. Disinfectant is the last treatment applied to water.

1.8 Sedimentation Theory

For separation of solid particles from water sedimentation is most widely used in waste water treatment. The separation process takes place in a settler. The influent with solids enters the sedimentation tank with feed in flow. Solids settles down and removed with the return flow. Clear water available at the top of the tank with effluent flow. For predict the behavior of the sedimentation tank a mathematical model can be used. Most of the continuous sedimentation models are based on the theory introduced by Kynch [4] according to which the settling velocity of solids particles depends only on the local suspended solids concentration. A scalar conservation law in the form of a partial differential equation can define the process. Concentration discontinuities are present in this model and it is difficult to classify the steady-state solutions for changing feed flux values (different values of feed flow and feed concentration). Those discontinuities are introduced by the point source at the feed of solids and by the two outlets (top and bottom) of the settler. Fig. 2 shows the process of sedimentation which is considered for model development, where Qf is the feed flow of solids suspended in water into the sedimentation tank; Qr, the return flow of settle down particles; Qe, the effluent flow of cleared water (overflow); A, the cross-sectional area of the sedimentation; xe, the height of the settler; xf, the height of the feed point into the settler; Din, the depth of the feed zone and x is the space variable.

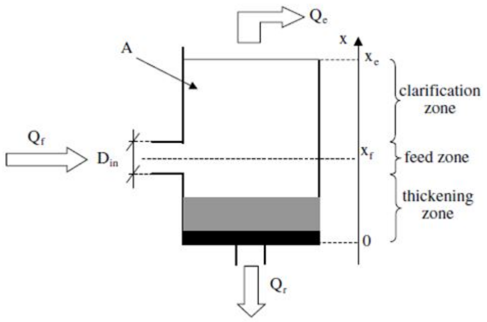

Figure 1.2: Process Under consideration.

The inlet pipe through which water containing suspended particles is entering the settler is connected to the side of the settler (Qf flow). The solids suspended in the water are settling gravitationally and water with condensed particles is removed from the settler with the return flow Qr. The cleared water is removed from the top of the settler with the effluent flow Qe. In a well-operated settler, the whole suspended solids are removed with the return flux and the suspended solids concentration in the effluent in minimal. If however, the incoming flow is greater than the limiting flux the settler is no longer capable of settling the whole mass of solids and high concentration of suspended solids is present in the effluent. In this case the settler is overloaded. One-dimensional modelling of sedimentation process is generally based on the following assumptions:

- The velocity of solid particles depends only on the local suspended solids concentration.
- Only the vertical movement of particles is considered and the horizontal gradients in concentration are negligible. The settler is therefore treated as a continuous flow reactor.
- The movement of solid particles is only due to gravitational settling and the bulk movement of water in the settler.
- The sedimentation takes place only inside the settler.

A scalar conservation law based on the conservation of mass can be derived. It is given by the following partial differential equation

$$\frac{\partial c}{\partial t} + \frac{\partial f(c, x, t)}{\partial x} = s(t)\delta(x - x_f) \tag{1.1}$$

Where c is the suspended solids concentration;
x is the space variable and
t is the time.
δ = Distribution constant.

F(c, x, t) is the total flux function defined as

$$f(c, x, t) = \begin{cases} wc, & FOR \ x > x_e \\ -\emptyset + wc & FOR \ x_e > x > x_f \\ -\emptyset - vc & FOR \ x_f > x > 0 \\ -vc & FOR \ \ 0 > x \end{cases}$$

Where $\emptyset$ = settling flux
and s(t) is the source function:

$$s(t) = \frac{Q_f C_f}{A} \tag{1.2}$$

Since the settling process takes place only inside the settler, above and below the settler the flux function is equal only to the flux caused by bulk movement of water. This causes discontinuities of the flux function at the boundaries of the settler (at x = 0 and x = xe). Another discontinuity is added to the flux function by the point source at the feed of solids into the settler (x = xf). The settling flux is expressed as

$$\emptyset = V_s c \tag{1.3}$$

Where v_s = settling velocity.

The below equation shows the relation between diameter of particle size with settling velocity [7].

$$V_s = \frac{RgD^2}{C_1 V + (0.75 C_2 RgD^3)^{0.5}} \tag{1.4}$$

Where

R = Specific gravity (1.65 for quartz in water)

g = Gravity Constant

D = Diameter of particle

Chapter 2

Literature survey

2.1 Review 1

Title: Modelling and controlling clarifier-thickeners fed by suspensions with time-dependent properties

Citation: Fernando Betancourt , Raimund Brger , Stefan Diehl , Sebastian Fars , Minerals Engineering 62 (2014) 91-101

Summery: A one-dimensional model of the process of sedimentation in a sedimentation tank is shown. The model is defined as a system of nonlinear partial differential equations for the settling velocity of the solids as functions of depth and time. Operating graphs were calculated to be used for the control of steady states. A numerical scheme and a simple controller are proposed and simulations studies are made. Can be developed more sophisticated control scheme e.g. PID Controller

2.2 Review 2

Title: Mathematical modelling of distributed feed in continuous sedimentation

Citation: Witold Nocon, Simulation Modelling Practice and Theory 14 (2006) 493-505

Summery: A One-dimensional modelling of continuous sedimentation process is presented in this paper. The process is defined by a scalar conservation law in the form of a partial differential equation. The future model upon discretisation includes a more number of layers in the feed section of the sedimentation tank. A comparison is prepared between the distributed source model and the typical only one point source model. It is observed that the obtained values of steady-state effluent and underflow concentrations are identical.

2.3 Review 3

Title: Simple mass balance controllers for continuous sedimentation
Citation: Fernando Betancourt, Fernando Concha,Daniel Sbrbaro, Computers and Chemical Engineering 54 (2013) 34- 43
Summery: This work shown a nonlinear PI controller which is able to soothe thickener operation using a simple control structure. An internationally accepted model and calibration using plant data is used to illustrate the design methodology and the level of performance attained by the controllers. The analysis of the results points out the improved performance by using extensive variables. In addition some guidelines concerning controllers tuning are also provided. Future work considers the analysis of the effect of flocculants in the performance of these controllers as well as the control of internal variables as the sediment level.

2.4 Review 4

Title: Mathematical model and numerical simulation of the dynamics of flocculated suspensions in clarifier-thickeners
Citation: Raimund Burger Kenneth H. Karlsen , John D. Towers
Summery: A mathematical model for continuous sedimentation processes of flocculated in sedimentation units is applied. The governing equation of this model is a scalar, strongly degenerate parabolic equation in which both the convective flux and the diffusion term depend on parameters that are discontinuous functions of the depth variable. A simple finite-difference scheme for the numerical solution of the model is introduced. We perform a limited analysis of steady states as desired stationary modes of operation.

2.5 Review 5

Title: Numerical modelling of sedimentation processes

Citation: David A. White, Nicola Verdone, Chemical Engineering Science 55 (2000) 2213

Summery: This paper considers the well-documented theory for the design of sedimentation tanks. The difference in this treatment is that a numerical model is used to do the necessary calculations for the limiting flux and the equations to do this are put in a dimensionless format. The model for a cylindrical settler is extended to the case of a conical settling geometry. It is shown that the conical settler can handle a wider range of solids loading. Finally, calculations are reported to estimate the characteristics of batch settling experiments for conical settlers and the results are compared with experimental data.

2.6 Review 6

Title: Steady-state, control, and capacity calculations for flocculated suspensions in clarifier-thickeners

Citation: Raimund Brger, Ariel Narvez, Int. J. Miner. Process. 84 (2007) 274-298

Summery: The model combines a theory of sedimentation-consolidation processes of flocculated suspensions, which leads to a strongly degenerate diffusion equation, with the discontinuous flux appearing in the recently analysed clarifier-thickener (CT) setup. This setup includes both clarification and thickening zones of clarifier-thickener units. The construction of steady-state concentration profiles attainable in a continuously operated CT is described. Numerical examples of steady-state profiles and their applications to comparisons between both modes of operation, to the control of sediment height through selection of the clarification/thickening split ratio of the feed flux, and for capacity calculations are presented. A numerical example illustrates the use of a numerical method for the full (time-dependent) model to compare several fill-up strategies.

Chapter 3

Modelling and simulation of sedimentation tank

3.1 Mathematical Model

Model of the process expressed by can be solved numerically by splitting up the settler into a number of horizontal layers. This leads to a set of ordinary differential equations which are than solved numerically. A discretised model is shown in Fig. 3.

By use of mass conservation, the set of ordinary differential equations can be derived as follows. Equation for feed in layer can be written as:

$$\frac{dC_m}{dt} = \frac{Q_f C_f}{A} - WC_m - VC_m - \phi_m \tag{3.1}$$

Equation for upper layer can be written as:

$$\frac{dC_e}{dt} = WC_m - \frac{C_e Q_e}{A} - \phi_e \tag{3.2}$$

Equation for below layer can be written as:

$$\frac{dC_r}{dt} = VC_m + \phi_m - \frac{C_r Q_r}{A} \tag{3.3}$$

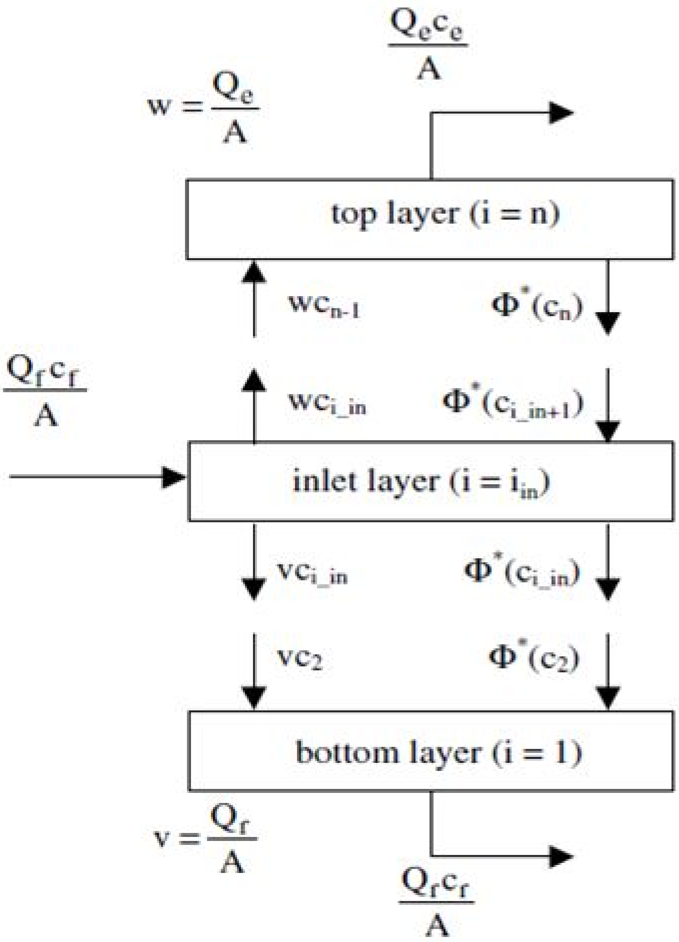

Figure 3.1: Discretised model of sedimentation tank.

3.1.1 5-layer Model

For better understanding of the process, the model has been divided into five layers. Two more layers are added. One layer I added between feed-in layer and upper layer. Another layer is added between feed-in layer and bottom layer. The new model consists of five layers. Therefor five ordinary equations are required. Fig shows two additional layers in the model.

By use of mass conservation, the set of ordinary differential equations for five layer model can be derived as follows. The output concentration of each layer is noted as C1, C2, C3, C4 and C5 from top to bottom respectively. The process start from inlet layer i.e. concentration of inlet layer need to calculate at the starting point. Then based on inlet layer concentration all other concentration will be calculated.

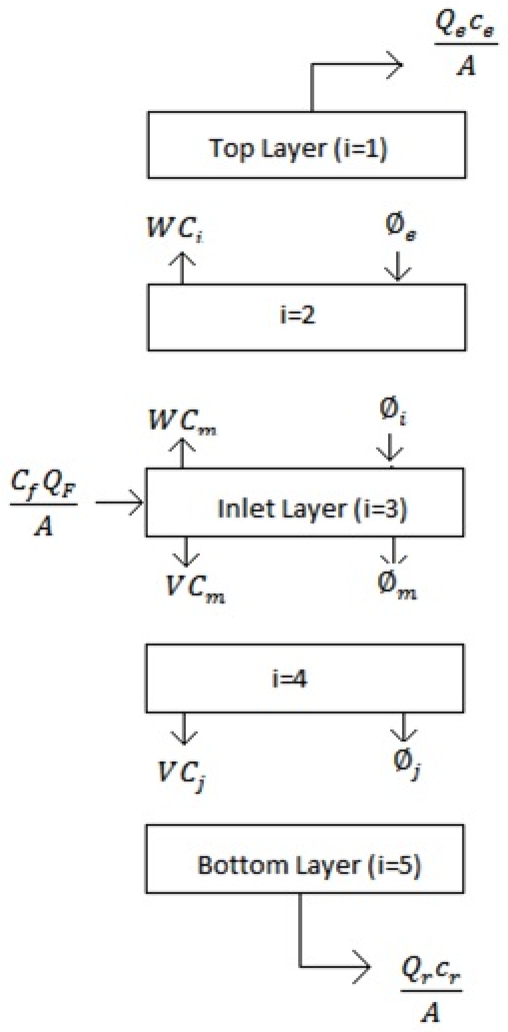

Figure 3.2: 5-Layer Discretised model of sedimentation tank.

Ordinary differential equation for the inlet layer can be

$$\Delta_z \frac{dC_3}{dt} = \frac{Q_f C_f}{A} - WC_3 - VC_3 - \phi_3 + \phi_2 \tag{3.4}$$

Where

C_3 = Concentration of inlet layer (kg/m^3)

C_f = Feed in Concentration (kg/m^3)

Q_f = Feed in flow (m^3/h)

W= Qe/A (m/h)

V= Qr/A (m/h)

ϕ_2= Flux enter from 2^{nd} layer

ϕ_3= Flux exits from inlet layer

Now ODE for second layer can be written as

$$\Delta_z \frac{dC_2}{dt} = WC_3 - WC_2 - \phi_2 + \phi_1 \tag{3.5}$$

where

C_2 = Concentration of 2^{nd} layer (kg/m^3)

C_3 = Concentration of inlet layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_2= Flux exits from 2^{nd} layer

ϕ_1= Flux enter from 1^{st} layer

ODE for the top layer is

$$\Delta_z \frac{dC_1}{dt} = WC_2 - \frac{C_1 Q_e}{A} - \phi_1 \tag{3.6}$$

Where

C_1= Concentration of 1st layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_1= Flux exits from 1^{st} layer

ϕ_e = Flow of effluent (kg/m^3)

ODE for the fourth layer can be written as

$$\Delta_z \frac{dC_4}{dt} = VC_3 - VC_4 - \phi_4 + \phi_3 \tag{3.7}$$

Where

C_4= Concentration of 4th layer (kg/m^3)

V= Qr/A (m/h)

ϕ_3= Flux coming from inlet layer

ϕ_4= Flux exits from 4th layer

ODE for the last layer

$$\frac{dC_5}{dt} = VC_3 + \phi_4 - \frac{C_r Q_r}{A} \tag{3.8}$$

Where

C_5= Concentration of 5th layer (kg/m^3)

V= Qr/A (m/h)

ϕ_4= Flux coming from 4th layer

3.1.2 7-layer Model

For better understanding of concentration profile model is divided in to seven layers. Schematic diagram of seven layer model is shown below. It shows that three layers are above feed in layers and three layers are below feed in layers. By use of mass conservation, the set of ordinary differential equations for seven layer model can be derived as follows. The output concentration of each layer is noted as C1, C2, C3, C4, C5, C6 and C7 from top to bottom respectively. The process start from inlet layer i.e. concentration of inlet layer need to calculate at the starting point. Then based on inlet layer concentration all other concentration will be calculated.

Ordinary differential equation for the inlet layer can be

$$\Delta_z \frac{dC_4}{dt} = \frac{Q_f C_f}{A} - WC_4 - VC_4 - \phi_4 + \phi_3 \tag{3.9}$$

Where

C_4 = Concentration of inlet layer (kg/m^3)

C_f = Feed in Concentration (kg/m^3)

Q_f = Feed in flow (m^3/h)

W= Qe/A (m/h)

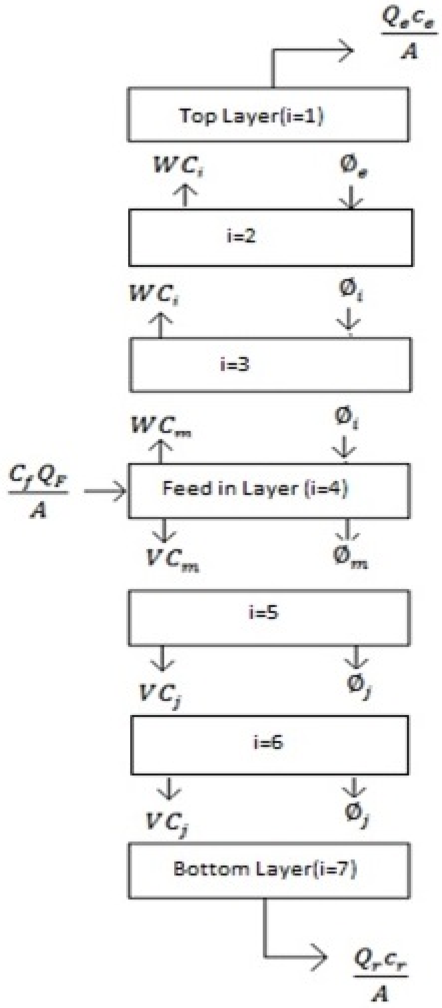

Figure 3.3: 7-Layer Discretised model of sedimentation tank.

V= Qr/A (m/h)

ϕ_3= Flux enter from 3^{nd} layer

ϕ_4= Flux exits from inlet layer

Now ODE for third layer can be written as

$$\Delta_z \frac{dC_3}{dt} = WC_4 - WC_3 - \phi_3 + \phi_2 \tag{3.10}$$

where

C_3 = Concentration of 3^{nd} layer (kg/m^3)

C_4 = Concentration of inlet layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_3= Flux exits from 3^{rd} layer

ϕ_2= Flux enter from 2^{nd} layer

ODE for the top layer is

$$\Delta_z \frac{dC_1}{dt} = WC_2 - \frac{C_1 Q_e}{A} - \phi_1 \tag{3.11}$$

Where

C_1= Concentration of 1st layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_1= Flux exits from 1^{st} layer

ϕ_e = Flow of effluent (kg/m^3)

ODE for the fifth layer can be written as

$$\Delta_z \frac{dC_5}{dt} = VC_4 - VC_5 - \phi_3 + \phi_4 \tag{3.12}$$

Where

C_4= Concentration of 4th layer (kg/m^3)

V= Qr/A (m/h)

ϕ_3= Flux coming from inlet layer

ϕ_4= Flux exits from 4th layer

ODE for the sixth layer can be written as

$$\Delta_z \frac{dC_6}{dt} = VC_5 - VC_4 - \phi_4 + \phi_5 \tag{3.13}$$

Where

C_5= Concentration of 5th layer (kg/m^3)

V= Qr/A (m/h)

ϕ_5= Flux coming from fifth layer

ϕ_4= Flux exits from fourth layer

ODE for the last layer

$$\frac{dC_5}{dt} = VC_6 + \phi_6 - \frac{C_r Q_r}{A} \tag{3.14}$$

Where

C_6= Concentration of 6th layer (kg/m^3) V= Qr/A (m/h) ϕ_6= Flux coming from 5th layer

3.1.3 Distributed source function model

Till now, it is assumed that the input of the model is only affected to one layer i.e. feed in layer. On bases of that all the ODEs are developed and simulation have been done. The results show that it only affects the concentration of the feed in layer. For good approximation from the model input should be distributed in to more numbers of layer.

In new idea of modelling the input is distributed to numbers of layer. So, not only just feed in layer but also some layer from upper and some layers from below are affected due to feed in change. Change in feed in will maximum affect the feed in layer and then effect of change become decreasing with increasing in distance from feed in layer. So far concentration change only affect the feed in but in new modelling method it affect the more than one layer that makes difference in simulation results. Figure shows the comparison between new model and old model. Here for simulation purpose only five layer model is shown. In new model it is considered that feed in layer is 50% affected by the change in input. Two more layers affected by input change, one is above the feed in layer and another is below feed in layer. Considering that both layer affected 25% by change in input.

One bases of the new model set of ODEs can be derived as below. Ode for the feed in layer can be written as Ordinary differential equation for the inlet layer can

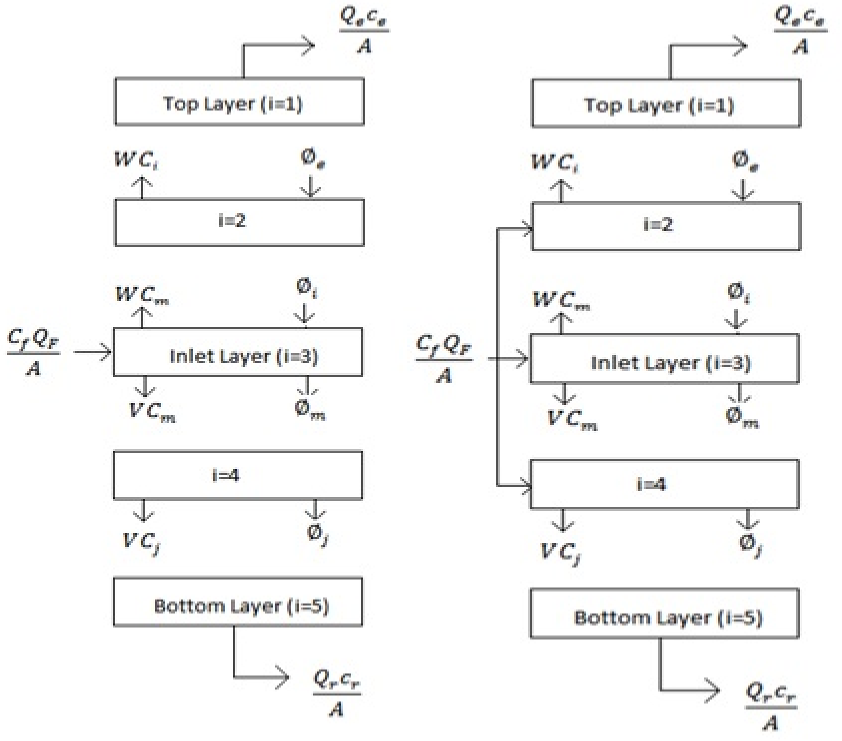

Figure 3.4: Previous model with input affected to one layer and model with distributed input to more than one layer.

be

$$\Delta_z \frac{dC_3}{dt} = 0.5 \frac{Q_f C_f}{A} - WC_3 - VC_3 - \phi_3 + \phi_2 \tag{3.15}$$

Where

C_3 = Concentration of inlet layer (kg/m^3)

C_f = Feed in Concentration (kg/m^3)

Q_f = Feed in flow (m^3/h)

W= Qe/A (m/h)

V= Qr/A (m/h)

ϕ_2= Flux enter from 2^{nd} layer

ϕ_3= Flux exits from inlet layer

Now ODE for second layer can be written as

$$\Delta_z \frac{dC_2}{dt} = 0.25\frac{Q_f C_f}{A} + WC_3 - WC_2 - \phi_2 + \phi_1 \tag{3.16}$$

where

C_2 = Concentration of 2^{nd} layer (kg/m^3)

C_3 = Concentration of inlet layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_2= Flux exits from 2^{nd} layer

ϕ_1= Flux enter from 1^{st} layer

ODE for the top layer is

$$\Delta_z \frac{dC_1}{dt} = WC_2 - \frac{C_1 Q_e}{A} - \phi_1 \tag{3.17}$$

Where

C_1= Concentration of 1st layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_1= Flux exits from 1^{st} layer

ϕ_e = Flow of effluent (kg/m^3)

ODE for the fourth layer can be written as

$$\Delta_z \frac{dC_4}{dt} = 0.25\frac{Q_f C_f}{A} + VC_3 - VC_4 - \phi_4 + \phi_3 \tag{3.18}$$

Where

C_4= Concentration of 4th layer (kg/m^3)

V= Qr/A (m/h)

ϕ_3= Flux coming from inlet layer

ϕ_4= Flux exits from 4th layer

ODE for the last layer

$$\frac{dC_5}{dt} = VC_3 + \phi_4 - \frac{C_rQ_r}{A} \tag{3.19}$$

Where

C_5= Concentration of 5th layer (kg/m^3) V= Qr/A (m/h) ϕ_4= Flux coming from 4th layer

3.2 Simulation studies

Simulation studies were performed using MATLAB environment. The dimensions of the settler were chosen as follows: Qf = 1300 m^3 /h
Cf = 3.08 kg/m^3
Qe=800 m3/h
Qr=500 m3/h
A = 1260 m2
Settling velocity (vs) = 6.56 m/s2
The following parameters of the settling velocity function were used: Specific gravity (R) = 1.65 quartz for water
Viscosity =1.0 * 10-6 kg/ms
Solids Diameter (D) = 0.2 mm
C1=18 and C2=1 for sand.

Based on this data constants for the process can be derived as:
W = Q_e /A = 0.6349 m/h
V = Q_r /A = 0.3968 m/h
The initial suspended solids concentration in the settler is assumed to be zero.

3.2.1 Simulation of Five layer model

The system of mass balance ordinary differential equation can be solved using solver of MATLAB. Simulation results show the each layer concentration with change in input flow and feed in concentration. Also how the concentration of each layer change with change in area of tank is shown.
Figure3.5 shows the concentration profile through settler with time. It shows that concentration in the settler is uniform with exception of the sharp spatial transition. This was also observed in reference [2]. This sharp spatial transition is not physical but, results from the discrimination scheme. This can be refined by adding the gravitational fluxes.

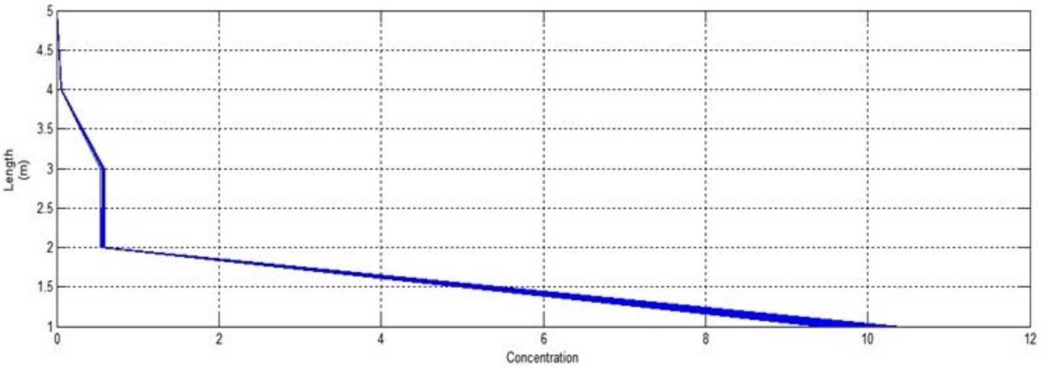

Figure 3.5: Concentration profile for settler with 10 % change in feed in flow(Q_f)

Change in feed in flow

Following figures represent the change in concentration of each layer with 10% change in feed in flow. By observing the concentration profile it is concluded that the change in concentration in bottom layer is more significant than the change in concentration in top most layer.

By increasing the area of the tank, each layer of concentration takes more time to reach steady state. So, ultimately the transient period for concentration is increased with increment in area. For large area tank the change of concentration in top layer is lesser than the same in small area tank.

Fig3.6 shows the Simulink result for top most layer i.e. in this case 1st layer. Fig3.7 include the change in 2nd layer with feed in flow, Fig3.8 shows change in inlet layer concentration, fig3.9 shows the 4th layer concentration and bottom layer concentration is shown in fig3.10.

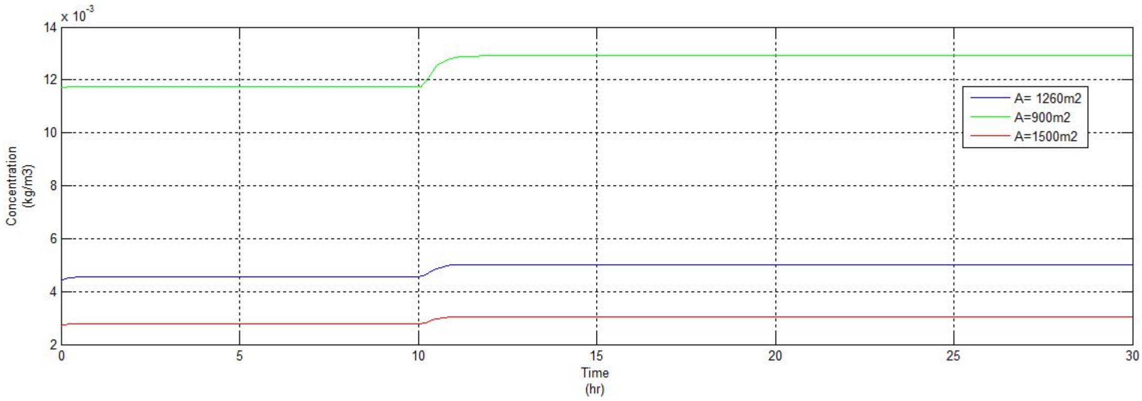

Figure 3.6: Concentration change in top layer with change in input flow Qf (i=1)

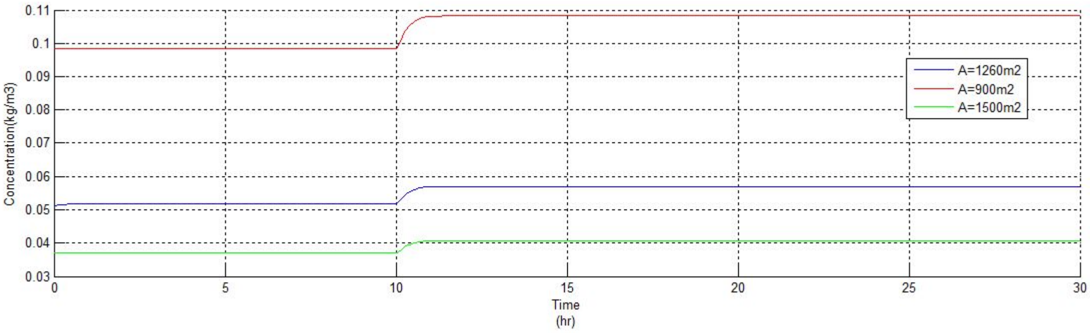

Figure 3.7: Concentration change in second layer with change in input flow Qf (i=2)

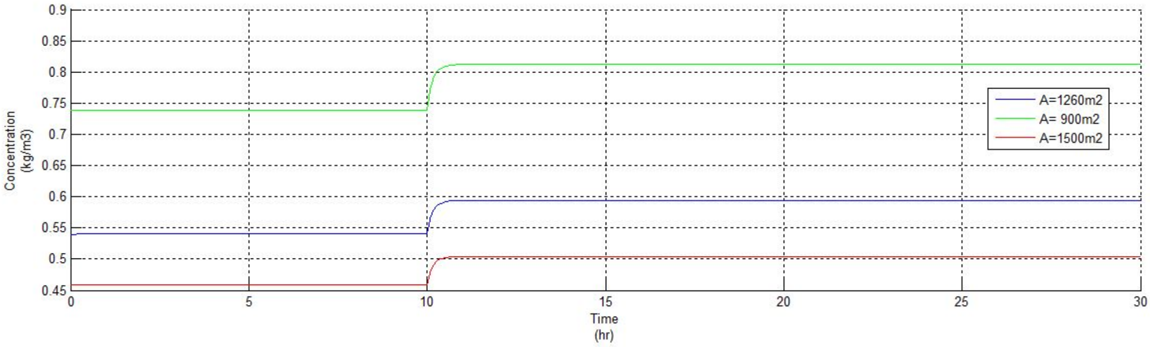

Figure 3.8: Concentration change in third layer with change in input flow Qf (i=3)

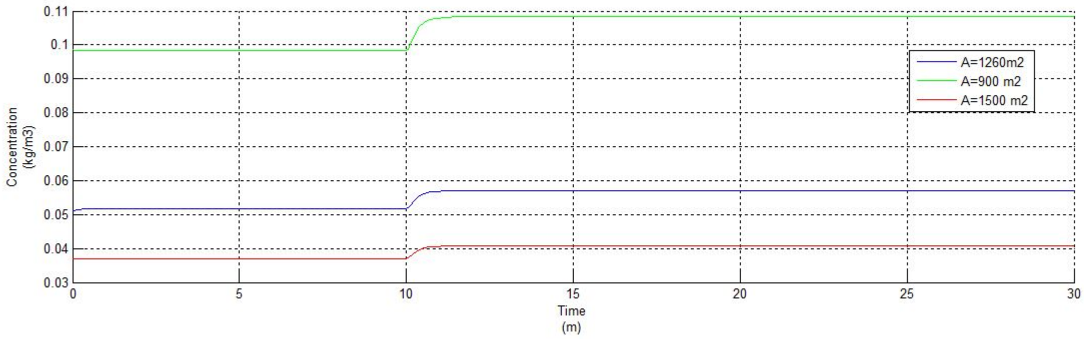

Figure 3.9: Concentration change in fourth layer with change in input flow Qf (i=4)

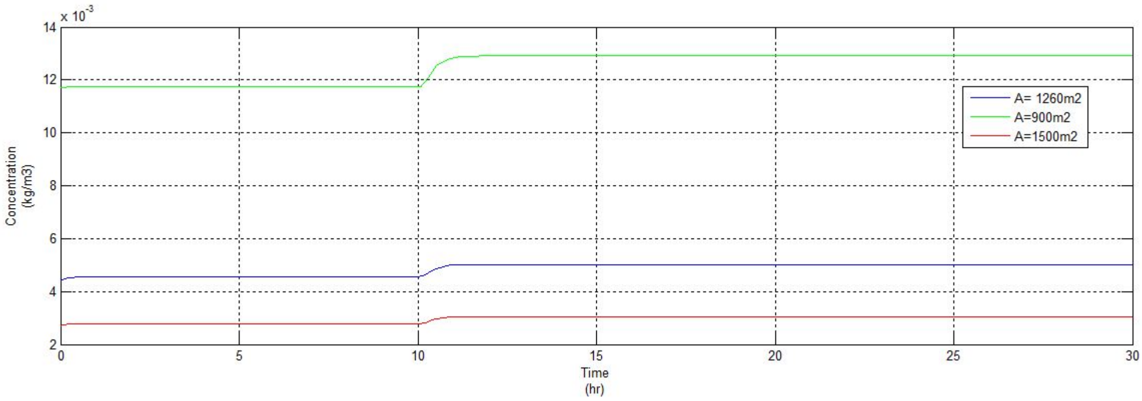

Figure 3.10: Concentration change in bottom layer with change in input flow Qf (i=5)

3.2.2 Simulation of Seven layer model

By using sets of differential equation Simulation results show the each layer concentration with change in input flow and feed in concentration. Fig 3.11 to fig 3.17 shows the concentration change in each layer with 10% change in source function.

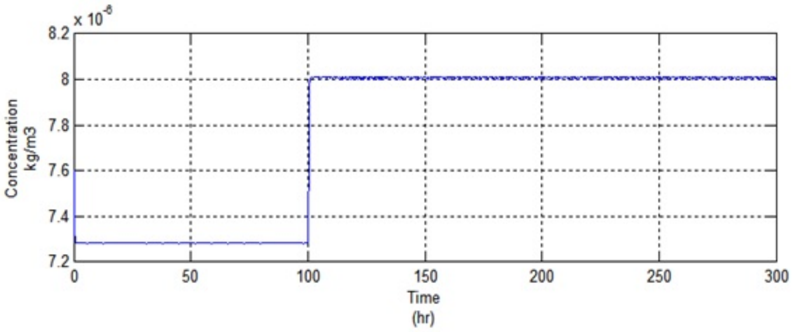

Figure 3.11: Concentration change in bottom layer with 10 % change in feed in flow(Q_f)

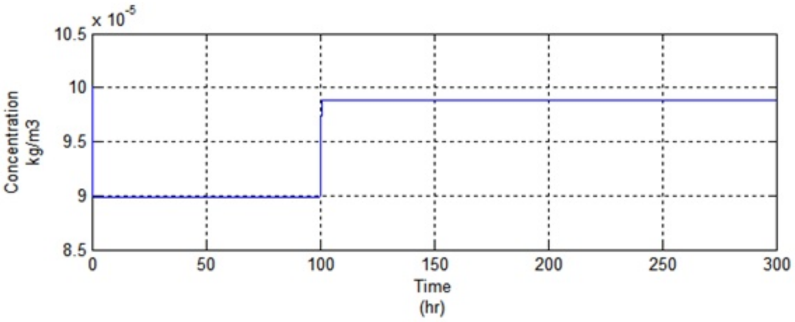

Figure 3.12: Concentration change in second layer with 10 % change in feed in flow(Q_f)

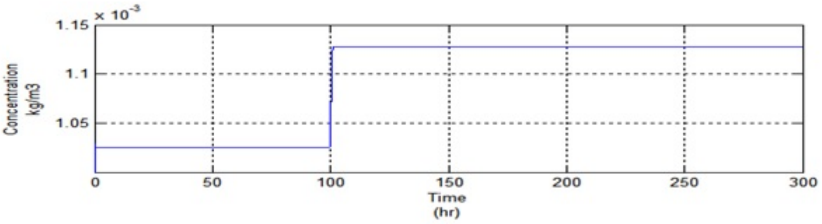

Figure 3.13: Concentration change in third layer with 10 % change in feed in flow(Q_f)

3.2.3 Simulation of model with distributed source function

The numerical values used in this study are same as used for previous model. The only difference is that this model has distributed it source function. Simulation results show the each layer concentration with change in input flow and feed in concentration. Also how the concentration of each layer change with change in area of tank is shown.

Simulation results shows the each layer due to 10% change in source function. Feed in flow of influent is increased by 10% i.e. at the start of the simulation flow is 1300 m3/hr and is taken to 1430 m3/hr. Simulation results are as shown below.

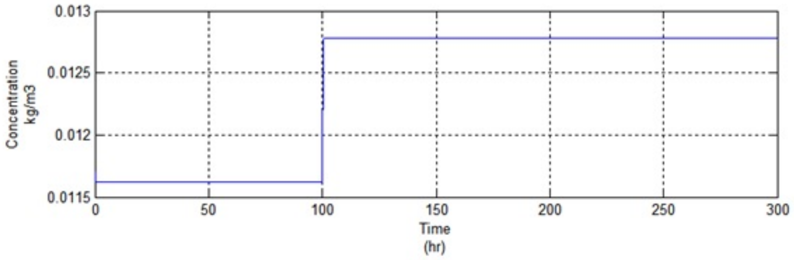

Figure 3.14: Concentration change in fourth layer with 10 % change in feed in flow(Q_f)

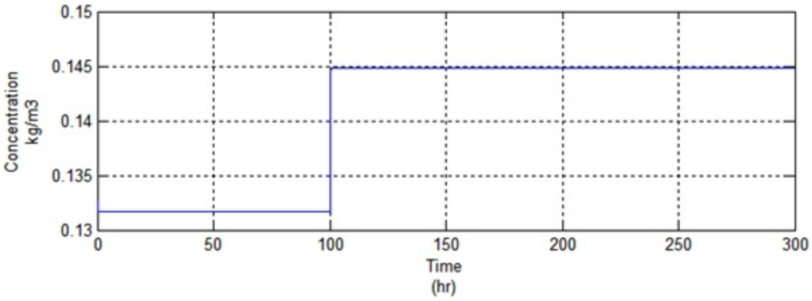

Figure 3.15: Concentration change in fifth layer with 10 % change in feed in flow(Q_f)

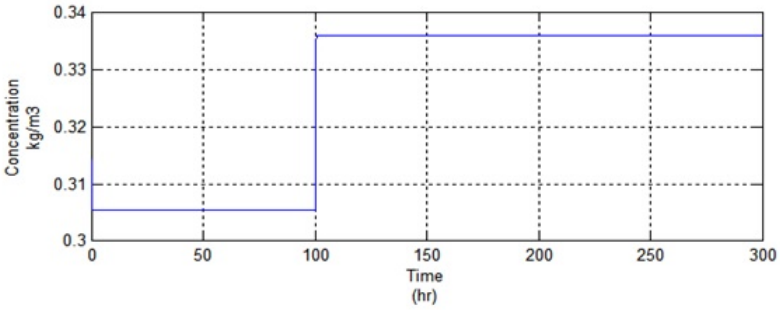

Figure 3.16: Concentration change in sixth layer with 10 % change in feed in flow(Q_f)

Fig3.12 shows change in concentration of top layer, at the starting time the concentration was 0.01595 kg/m3 after 10% change in input it goes to 0.0176 kg/m3 that shows the 6.53% change in top layer. At the starting time the concentration was 0.1808 kg/m3 after 10% change in input it goes to 0.198 kg/m3 that shows the 5.55% change in 2nd layer. At the starting time the concentration was 0.40389 kg/m3 after 10% change in input it goes to 0.4450 kg/m3 that shows the 8.9% change in 3rd layer. At the starting time the concentration was 0.53901 kg/m3 after 10% change in input it goes to 0.5950 kg/m3 that shows the 8.9% change in 4th layer. At the starting time the concentration was 9.450 kg/m3 after 10% change in input it goes to 10.422 kg/m3 that shows the 10.15% change in 5th layer.

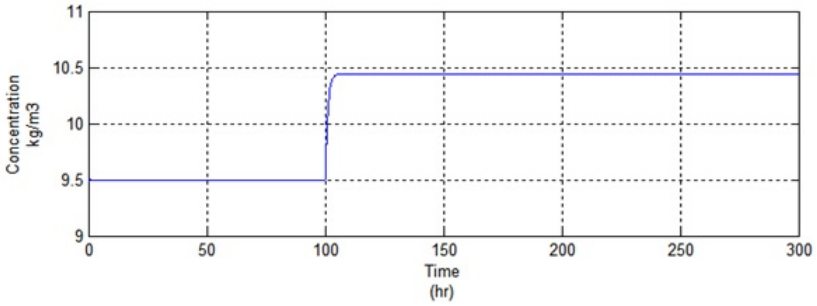

Figure 3.17: Concentration change in bottom layer with 10 % change in feed in flow(Q_f)

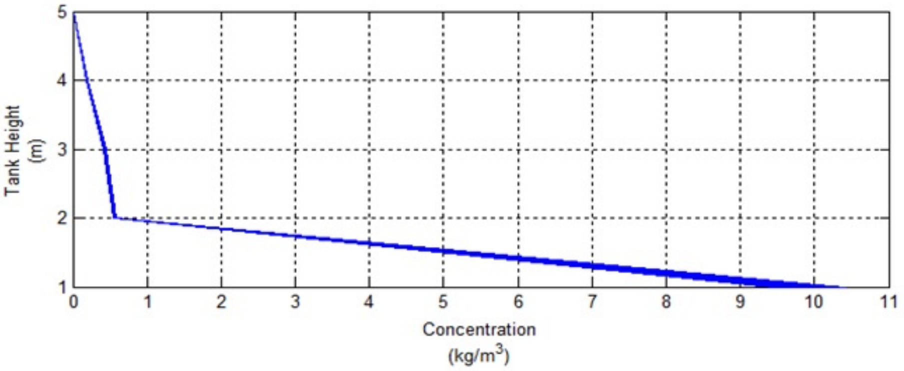

Figure 3.18: Concentration profile for settler with 10 % change in feed in flow(Q_f)

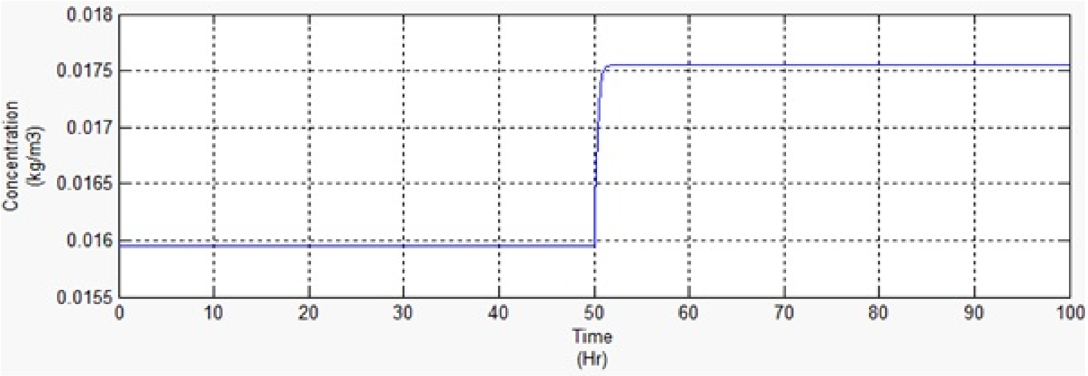

Figure 3.19: Change in concentration of top layer.

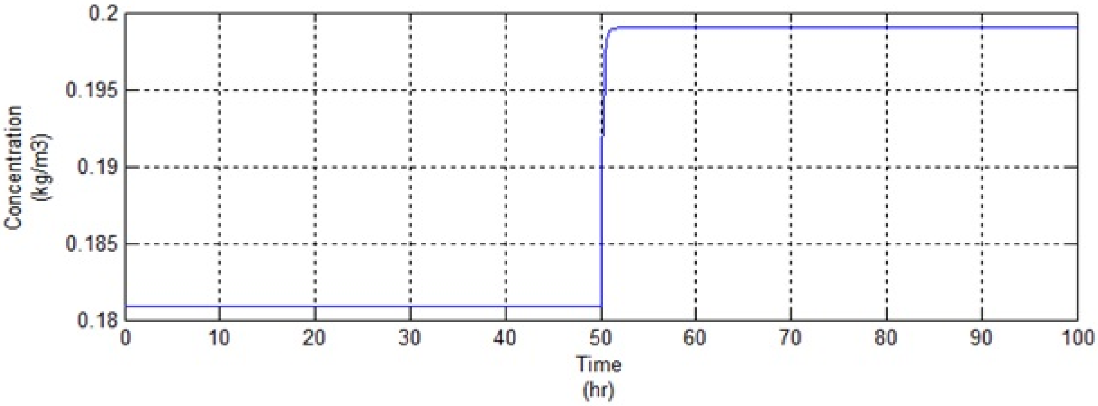

Figure 3.20: Change in concentration of 2nd layer.

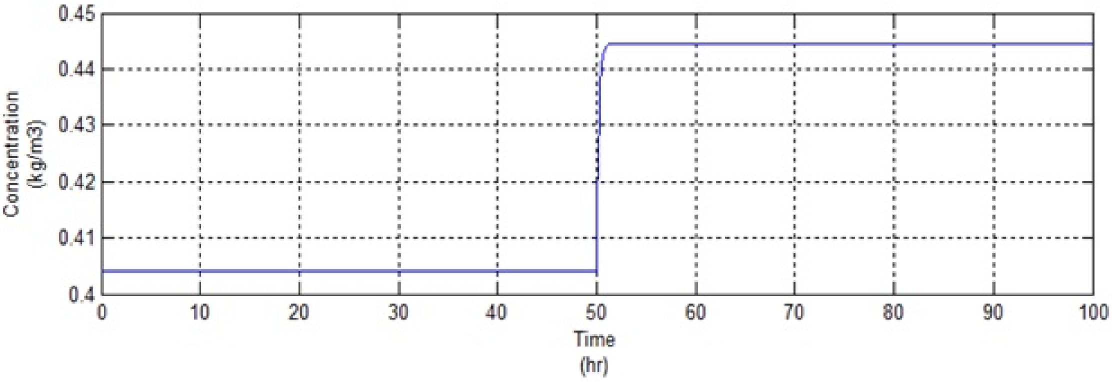

Figure 3.21: Change in concentration of 3rd layer.

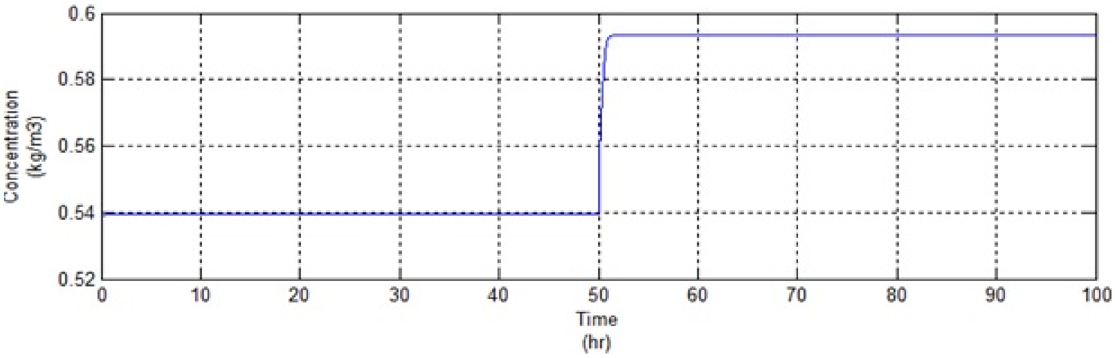

Figure 3.22: Change in concentration of 4th layer.

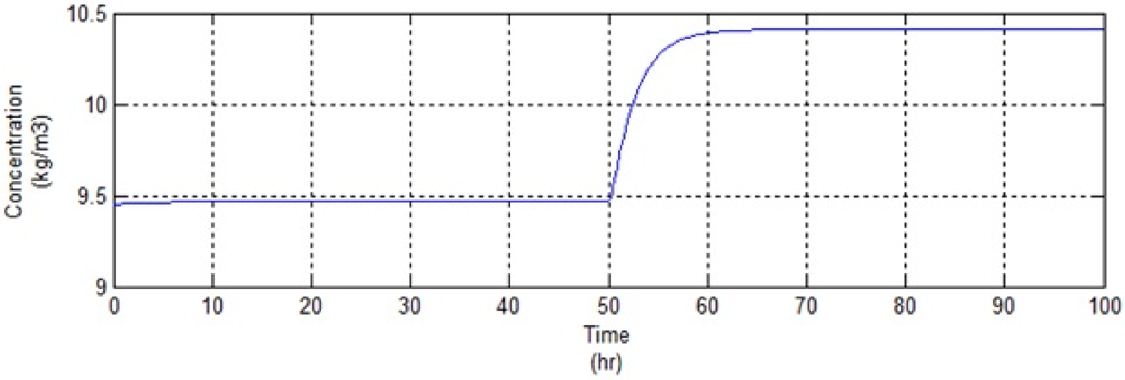

Figure 3.23: Change in concentration of 5th layer.

Chapter 4

Development of on-site model CETP- VATVA

For validation of the developed model, ”Common effluent treatment plant (CETP)” located at VATVA is selected. The 680 member units of the estate are spread in an area of 13.5 sq. km. in Vatva industrial estate. The effluent from each member unit is conveyed through internal collection System to CETP in a systematic manner. Adequate arrangement is made for monitoring quality and quantity of effluent from each unit.

4.1 Treatment Process at CETP-Vatva

The CETP consist of the following unit.

- Equalization Tank
- Flash Mixer
- Clary Flocculator
- Dissolved Air Floatation Unit
- Aeration Tank
- Secondary Clarifiers

The pre-treated effluent from the member units is pumped to the Equalization Tank. The Equalization tank is designed to provide residence time of 24 hours under the maximum flow condition. The contents of the Equalization Tank are thoroughly mixed equalized with the help of coarse bubble diffused aeration supplemented by a Turbo Aerator[8].

From the Equalization Tank the wastewater flows through flow-control arrangement into Flash Mixer where coagulants and flocculants are added. After complete mixing of the chemicals with the effluent it flows into Flocculator where coagulation and flocculation of suspended solids, colloids and some of the dissolved pollutants take place. The overflow from the Flocculator goes to Dissolved Air Floatation (DAF) Unit. The unit works on the principle of super saturation of the liquid with dissolved air. The super saturation is achieved by mixing pressurized recycled wastewater with compressed air. The saturated recycle flow is released at about atmospheric pressure in the DAF Tank which results in the formation of fine bubbles. These fine bubbles get attached with flocculated particles and are floated to the top of the tank. These particles as well as those settled at the bottom of the tank are removed and collected by the top and bottom scrappers in the form of primary sludge and is collected in the Primary Sludge Holding Tank from where it is sent to Centrifuge Decanter for dewatering. The dewatered sludge is then disposed of into Secured Landfill Site at Vinzol[8].

4.2 Sedimentation Process at CETP- Vatva

The sediment tank at CETP-Vatva is circular type clary flocculator. Till now for development of model vertical type sediment tank was considered. The schematic diagram of circular tank with the flow direction is shown below. In this type of tank water enter from the bottom of the tank and then heavy particles settle down and clear water will be available at the top of settler. The sludge collected at the bottom of the tank is removed from bottom.

The basic difference between vertical sediment tank and circular tank is change of

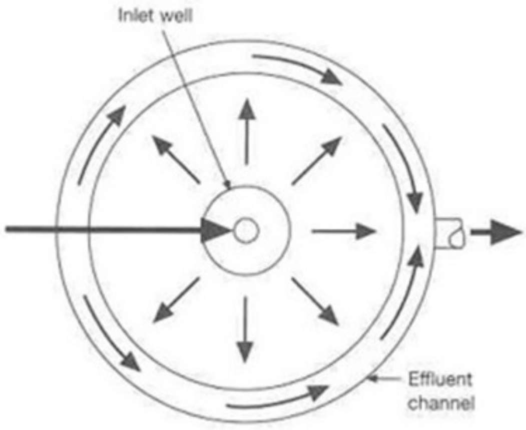

Figure 4.1: Sedimentation process at CETP-Vatva

location of inlet of the influent. In vertical tank, influent enter the tank at the middle of the tank while in circular tank influent enters from bottom of the tank. In this process heavy particles settle down and clear water available at the top of the tank. For better understanding of process tank is divided in to 8 equal parts and developed mathematical model for each equal part.

4.3 Development of mathematical Model

Model of the process expressed by can be solved numerically by splitting up the settler into a number of horizontal layers. This leads to a set of ordinary differential equations which are than solved numerically. A discretised model is shown in fig 4.2.

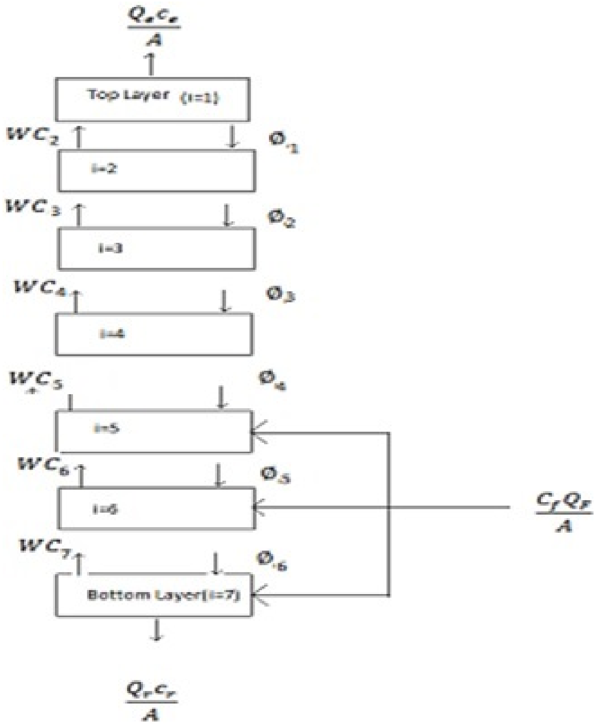

Figure 4.2: Discritized model of sediment tank at CETP-Vatva

By use of mass conservation, the set of ordinary differential equations for three layer model can be derived as follows. From top to bottom the concentration of layer are described as C1, C2, C3, C4, C5, C6 and C7. The process starts from bottom of the tank from where the influent enter the tank. It is assumed that input affects to the bottom layer is maximum and as the height increases the effect of input to layer become decreased.

By use of mass balance equation the ODE for top layer can be

$$\Delta_z \frac{dC_1}{dt} = -WC_1 - WC_2 - \phi_1 \tag{4.1}$$

C_1 = Concentration of top layer (kg/m^3)

C_2 = Concentration of second layer (kg/m^3)

ϕ_1= Flux of top layer

Now ODE for second layer can be written as

$$\Delta_z \frac{dC_2}{dt} = WC_3 - WC_2 - \phi_2 + \phi_1 \tag{4.2}$$

where

C_2 = Concentration of 2^{nd} layer (kg/m^3)

C_3 = Concentration of 3^{nd} layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_1= Flux exits from 1^{st} layer

ϕ_2= Flux enter from 2^{nd} layer

Now ODE for third layer can be written as

$$\Delta_z \frac{dC_3}{dt} = WC_4 - WC_3 - \phi_3 + \phi_2 \tag{4.3}$$

where

C_4 = Concentration of 4^{th} layer (kg/m^3)

C_3 = Concentration of 3^{rd} layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_2= Flux enter from 2^{nd} layer

Now ODE for fourth layer can be written as

$$\Delta_z \frac{dC_4}{dt} = WC_5 - WC_4 - \phi_4 + \phi_3 \tag{4.4}$$

where

C_4 = Concentration of 4^{th} layer (kg/m^3)

C_5 = Concentration of 5^{th} layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_4= Flux enter from 4^{th} layer

Now ODE for fifth layer can be written as

$$\Delta_z \frac{dC_5}{dt} = WC_6 - WC_5 - \phi_5 + \phi_4 + 0.2\frac{Q_f C_f}{A} \tag{4.5}$$

where

C_4 = Concentration of 4^{th} layer (kg/m^3)

C_5 = Concentration of 5^{th} layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_4= Flux enter from 4^{th} layer

Now ODE for sixth layer can be written as

$$\Delta_z \frac{dC_6}{dt} = WC_7 - WC_6 - \phi_6 + \phi_5 + 0.3\frac{Q_f C_f}{A} \tag{4.6}$$

where

C_6 = Concentration of 6^{th} layer (kg/m^3)

C_5 = Concentration of 5^{th} layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_6= Flux enter from 6^{th} layer

Now ODE for seventh layer can be written as

$$\Delta_z \frac{dC_7}{dt} = -WC_7 - vC_7 - \phi_7 + \phi_6 + 0.5\frac{Q_f C_f}{A} \tag{4.7}$$

where

C_6 = Concentration of 6^{th} layer (kg/m^3)

C_7 = Concentration of 7^{th} layer (kg/m^3)

W= Q_e/A (m/h)

ϕ_6= Flux enter from 6^{th} layer

4.4 Simulation studies

For simulation MATLAB environment is used. The dimensions of the settler were chosen as follows:

Here for better process understanding settler is divided in to 8 equal part. So each parameter related with settler must be divided in to 8 equal parts.

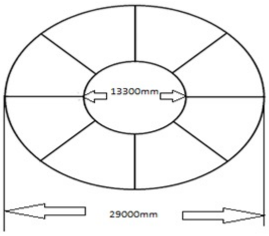

Figure 4.3: Top view with diameter of sediment tank at CETP-Vatva

To find the area of the tank

$$A = 2\Pi * h(R - r) \tag{4.8}$$

Where A= Cross section area of tank
h= height of the tank
R= Outer Radius of tank
r= Inner radius of tank
Using this equation total cross section area of the tank (A)= $172.54m^2$ And for each section area should be divided in to 8 part. So the cross section area for each layer A= $172.54/8 = 21.56m^2$

Total input flow, effluent flow and return flow are:

Qf = 1000 m3/h
Qe = 700 m3/h
Qr = 300 m3/h

On basis of the parameter taken from the sediment tank at CETP-Vatva the simulation is performed. The concentration profile of the sediment tank is shown in fig4.4.

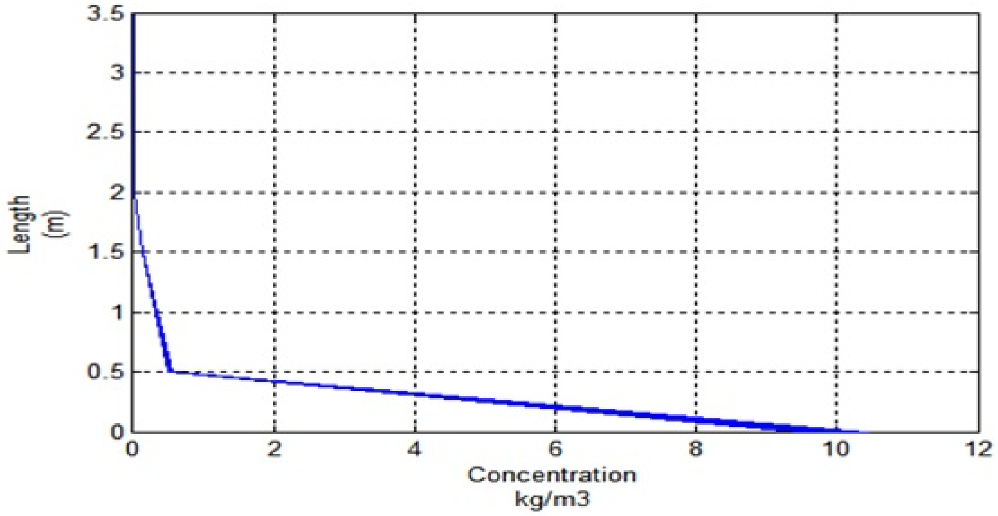

Figure 4.4: Concentration profile of sediment tank at CETP-Vatva

It shows that with increases in tank height concentration change will decreases. Maximum concentration occurs at the bottom of the tank. Concentration change in each layer with change in 10% input flow is shown below.

Fig4.5 shows at the starting time the concentration was 7.2×10^{-6} kg/^{3} after 10% change in input it goes to 8.01×10^{-6} kg/^{3} that shows the 8.75% change in top layer. Fig4.6 shows concentration of second layer at the starting time the concentration was 0.0001 after 10% change in input it goes to 0.00190 kg/^{3} that shows the 9.01% change in top layer.Fig4.7 shows concentration of third layer the starting time the concentration was 0.0010 kg/^{3} after 10% change in input it goes to 0.0011 kg/^{3} that shows the 9.09% change in top layer.At the starting time the concentration was 0.0117 kg/m3 after 10% change in input it goes to 0.012 kg/m^3 that shows the 8.59% change in top layer. At the starting time the concentration was 0.1326kg/m3 after 10% change in input it goes to 0.1448 kg/m3 that shows the 8.42%change in top layer.At the starting time the concentration was 0.5053 kg/m^3 after 10% change in input it goes to 0.5457 kg/m3 that shows the 7.40% change in top layer. At the starting time the concentration was 9.4883 kg/^{3} after 10% change in input it goes to 10.4390 kg/m^3 that shows the 9.03% change in top layer.

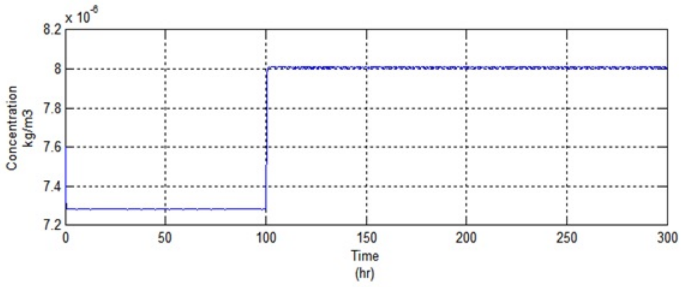

Figure 4.5: Change in concentration of top layer.

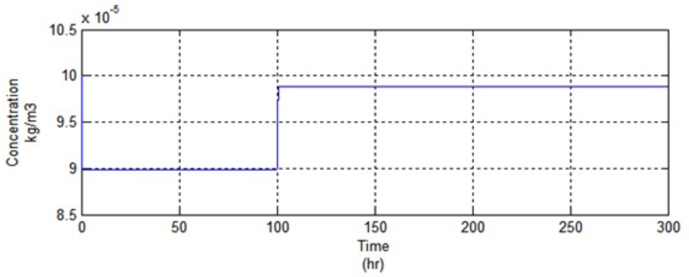

Figure 4.6: Change in concentration of second layer.

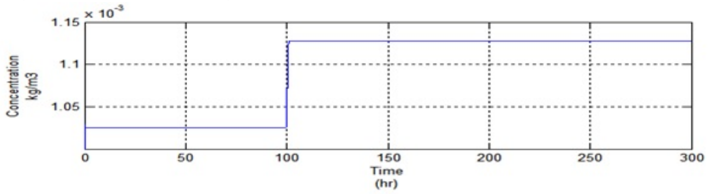

Figure 4.7: Change in concentration of third layer.

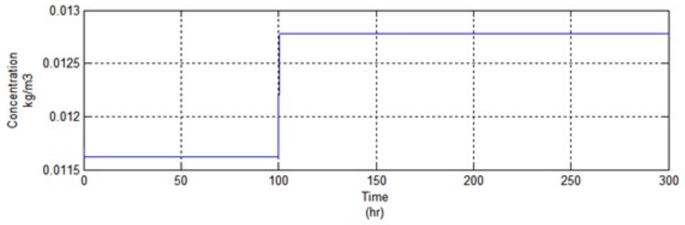

Figure 4.8: Change in concentration of fourth layer.

It is observed that there is mismatch between the simulator output and chemically analyzed output. The actual chemical analysis of the system is described in next section. So, it was necessary to tune the model. By taking source function as a

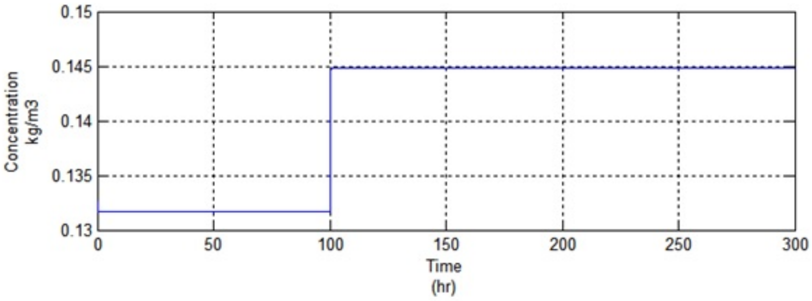

Figure 4.9: Change in concentration of fifth layer.

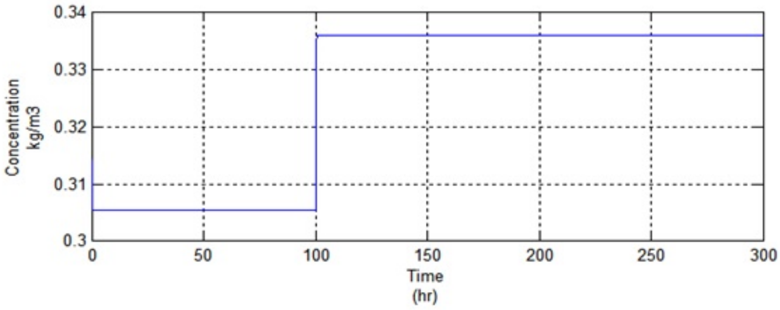

Figure 4.10: Change in concentration of sixth layer.

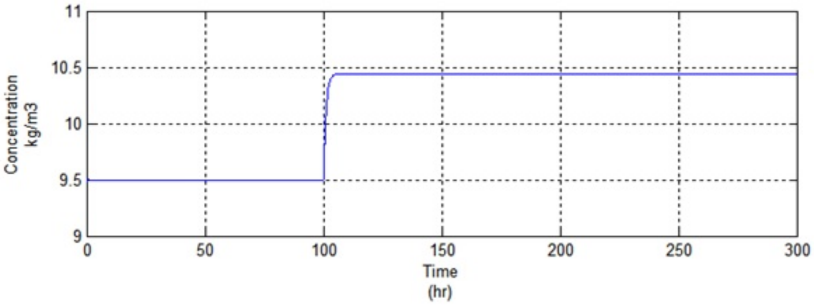

Figure 4.11: Change in concentration of bottom layer.

tuning parameter some simulation were performed. By changing source function, the simulator output matches with the actual chemically analyzed output. Fig 4.12 to fig 4.17 shows the result after modifying source function.

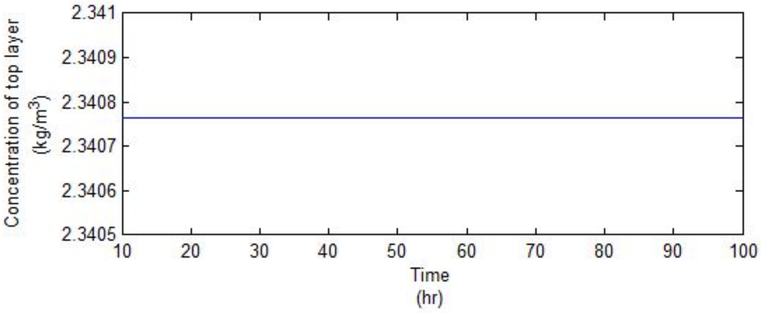

Figure 4.12: Concentration of top layer.

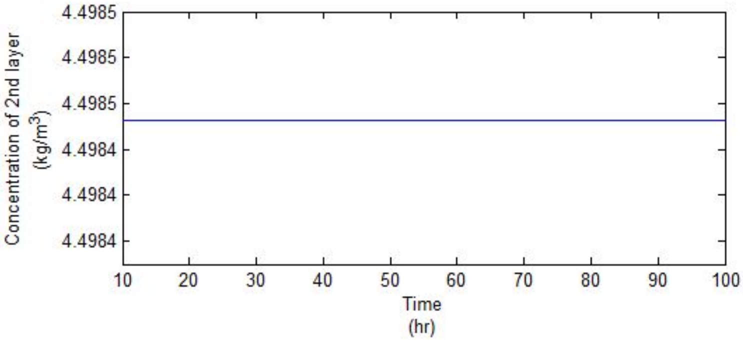

Figure 4.13: Concentration of 2nd layer.

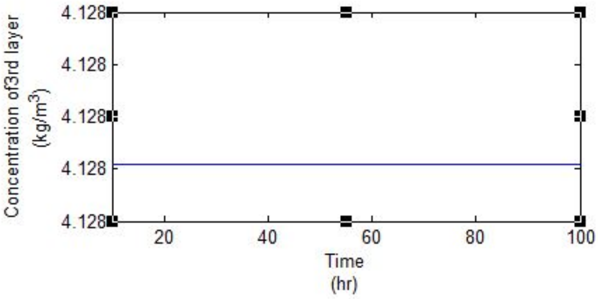

Figure 4.14: Concentration of 3rd layer.

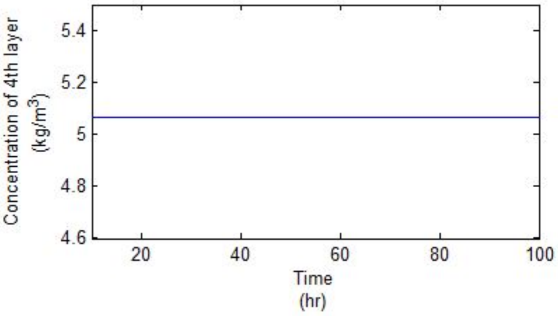

Figure 4.15: Concentration of 4th layer.

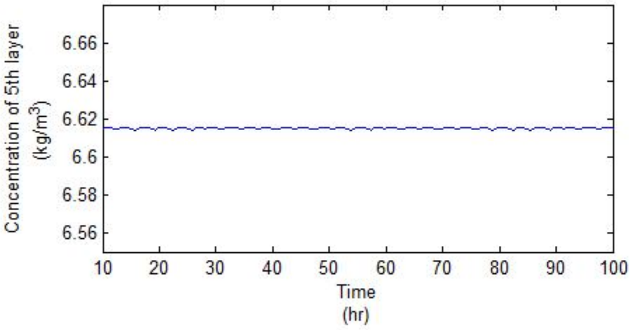

Figure 4.16: Concentration of 5th layer.

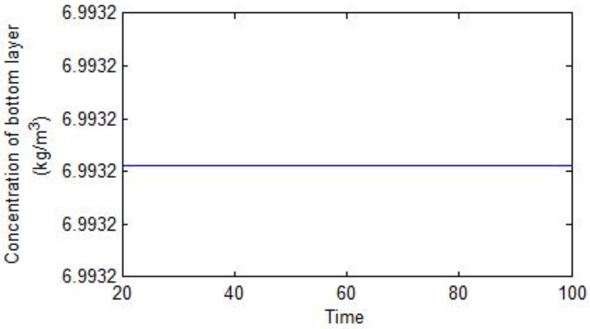

Figure 4.17: Concentration of bottom layer.

For proper validation, data of the same parameter were gathered from the same site location. Using the modifying source function simulator output was observed and it shows fine agreement with actual chemically analyzed output.
the values of new gathered data are as follows:

Qf = 800 m3/h

Qe = 600 m3/h

Qr = 200 m3/h

By using new flow rates new constants were defined and using the modifying source function.Fig4.18 to fig4.23 shows simulation results of each layer with new sample data.

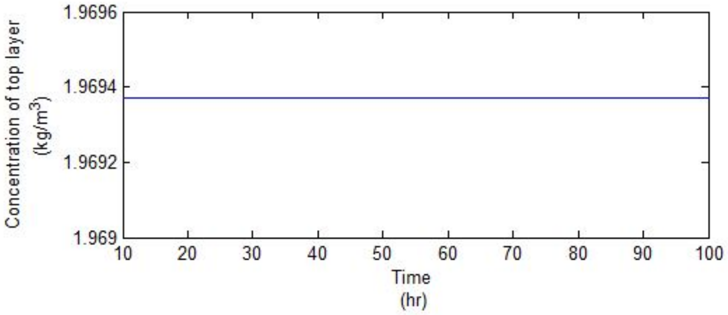

Figure 4.18: Concentration of top layer.

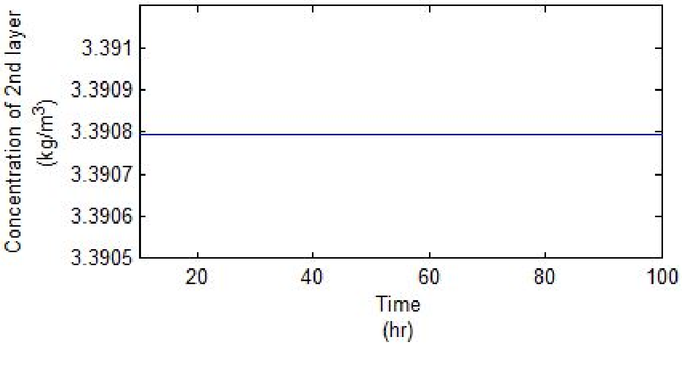

Figure 4.19: Concentration of 2nd layer.

4.5 Practical analysis of sediment sample

After collecting sample from sediment tank samples will be taken to the chemical laboratory for further analysis. From the analysis of laboratory concentration of each layer will be carried out. Steps for determination of solids from the sample is as follow:

a. Weigh a clean and dry whatman filter paper no 44 let this weigh =W1

b. Clean and oven dry the funnel at temp = 1041C

c. Shape and place the what man filter paper in to the funnel

d. Pour known volume of sample in to the funnel slowly and allow it to filter

e. After filtration carefully remove the filter paper and dry it in oven at 1041C temp for one hour.

f. Cool the filter paper in desiccators and weigh it as W2.

g. The increases in weigh gives the quantity of suspended solids for volume of sample.

4.6 Validation of Model

For validation of the model samples of sediment were gathered from the "Common effluent treatment plant- Vatva". The samples were taken from different heights of the tank as the developed model is discritized. Schematic diagram of taking sample is shown in appendix. For proper validation of the model two times data were collected and compared with simulated output. The data collected at the first time was used for tuning of the model and then for validation again sampling were done.

Table I: Observation Table

Tank Height(m)	Measured Value(kg/m^3)	Simulated Value(kg/m^3)	Error(%)
0.5	2.168	2.340	7.93
1.0	4.304	4.128	4.15
1.5	4.856	4.498	7.37
2.0	5.68	5.056	10.79
2.5	6.168	6.615	7.24
3.0	7.388	6.993	5.34

Table II: Observation Table for validation

Tank Height(m)	Measured Value(kg/m^3)	Simulated Value(kg/m^3)	Error(%)
0.5	1.982	1.9694	6.35
1.0	3.243	3.3908	4.55
1.5	3.953	3.8942	1.48
2.0	5.123	5.0748	0.94
2.5	5.983	5.702	4.68
3.0	7.154	7.200	6.48

Table I shows the comparison between actually measured value and simulated measured value of solid's concentration in each layer. At the time of sampling input flow was 1000 m^3/hr and input solids concentration was 9.188 kg/m^3. It is assumed that particle's diameter is $70\mu m$.

Without changing the model parameter different sample data were taken and again simulation were performed. Table 4.2 shows the comparison with actual measured value and simulated output value of solid's concentration of each layer. At the sampling time input flow(Q_f) to the sediment tank was 800 m^3/hr and input solid's concentration was 8.992 kg/m^3. Also, particle diameter were assumed to $70\mu m$.

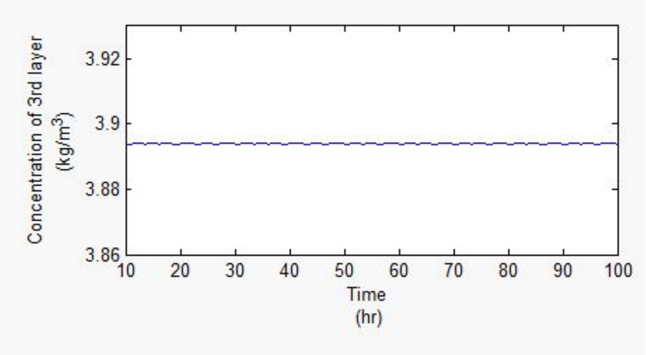

Figure 4.20: Concentration of 3rd layer.

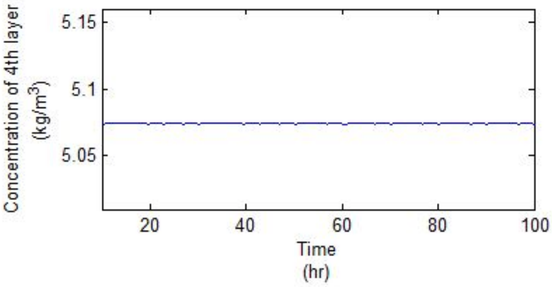

Figure 4.21: Concentration of 4th layer.

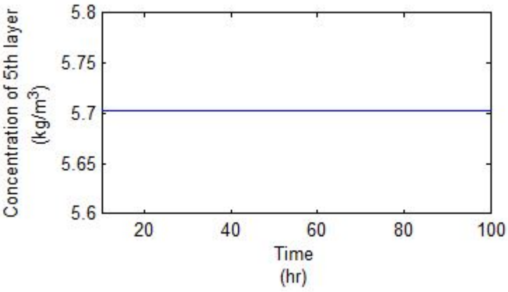

Figure 4.22: Concentration of 5th layer.

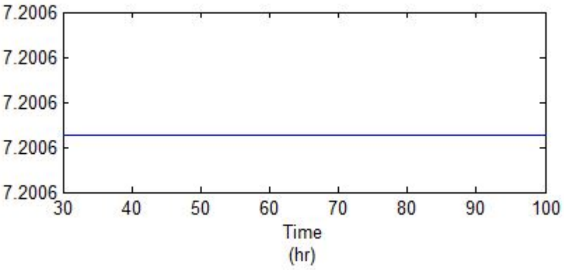

Figure 4.23: Concentration of bottom layer.

Chapter 5

Concluding remark and Future scope

5.1 Concluding remark

In this study the continuous sedimentation has been considered. The mathematical model of the sediment tank has been presented and validated with actual plant data. The developed model is discretized. Based on simulation studies performed it can be stated that this model is appropriate to study sedimentation process. It is clearly observed that the discretized source function gives better resolution as compared to one point source function model.

5.2 Future Scope

Soft sensing techniques can be applied for measurement of pollutants present in the waste water. Based on predicted concentration of settler pollutant analysis can be carried out. By adding the flocculant process model control strategies for dosing of flocculant can be developed. Also, parametric studies based on different parameters of sediment tank can be performed and validated with suitable experimental setup.

Appendix A

Appendix

A.1 Procedure for sampling

For validation of the model it need to take sample from sediment tank from different different height. Here for development of model tank is disctrised in to seven layer. So each layer is consist of 0.5 m length. So it is clear that from tank sample must be taken from increment of 0.5m depth i.e. sample must be taken from 0.5m ,1m, 1.5m, 2m, 2.5m, 3m and 3.5m. Schematic diagram for taking sampling is shown in fig1.
Equipments:

- Peristaltic pump
- Pipe
- Supporting Rod (1.5m)
- Sample collecting bottles
- Threads
- Labels
- Measuring Tape
- Marker

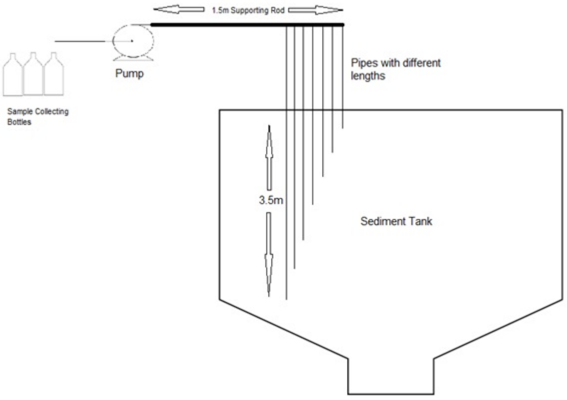

Figure A.1: Schematic diagram of taking sample from tank

Procedure:

a. Site survey.

b. Place the supporting rod at the position 1using the measuring tape as shown in figure for taking sample of sediment.

c. Starting with pipe of 0.5m length connects it with pump located on bridge and draw 100ml of water in bottle. Label the bottle according to the depth of the pipes.

d. Similar procedure described in step-4 will be carried out with pipe of different length mention in step-2.

e. Now change the location for sampling from position 1 to position 2 and repeat the procedure described in step 4.

f. Collected samples will be taken to Department of Chemical Engineering for further analysis.

A.2 Determination of suspended solids

Apparatus:

- Oven

Table I: Observation Table for TSS

Tank Height(m)	Measured Value(kg/m^3)	Simulated Value(kg/m^3)	Error(%)
0.5	2.168	2.340	7.93
1.0	4.304	4.128	4.15
1.5	4.856	4.498	7.37
2.0	5.68	5.056	10.79
2.5	6.168	6.615	7.24
3.0	7.388	6.993	5.34

- Whatman filter paper no 44
- Funnel and other glass wares

Procedure:

a. Weigh a clean and dry whatman filter paper no 44 let this weigh =W1

b. Clean and oven dry the funnel at temp = 104 ± 1^oC

c. Shape and place the what man filter paper in to the funnel

d. Pour known volume of sample in to the funnel slowly and allow it to filter

e. After filtration carefully remove the filter paper and dry it in oven at 1041C temp for one hour.

f. Cool the filter paper in desiccators and weigh it as W2.

g. The increases in weigh gives the quantity of suspended solids for volume of sample.

Observation Table:

A.3 COD test:

In COD test, 2.5ml sample, 1.5ml digestion solution and 3.5ml sulphuric acid reagent was taken in to tubes. The mixture in vials were digested for 2h at 150^oC in a heating block. The sample were allowed to cool and analyzed by the titration method. In this method the residual potassium dichromate in the digestion vial was titrated with 0.1 M ferrous ammonium sulphate (FAS) in the presence of ferroin indicator until the color of the sample changes from blue green color to red brown color. The amount of FAS used to achive the color change was recorded and used in the calculation of COD. The COD results of each layer is shown in table 2 for .

Table II: Observation Table for COD test

Tank Height(m)	COD(mg/lit)
0.5	800
1.0	1000
1.5	1000
2.0	1000
2.5	1200
3.0	1600

Table 3 shows the COD results for Q_f=800 m^3/h, C_f = 8.992 kg/m^3.

Table III: Observation Table for COD test

Tank Height(m)	COD(mg/lit)
0.5	800
1.0	960
1.5	960
2.0	960
2.5	960
3.0	1280

A.4 TOC test:

For total organic carbon test TOC analyzer is used which is available at the chemical department. All the guidelines were available at the chemical engineering department. Table IV shows the TOC results for Q_f=1000 m^3/h, C_f = 9.188 kg/m^3.

Table IV: Observation Table for TOC test

Tank Height(m)	TOC(ppm)
0.5	662.8
1.0	609.7
1.5	591.1
2.0	577.5
2.5	593.0
3.0	635.3

Table V shows the TOC results for Q_f=800 m^3/h, C_f = 8.992 kg/m^3.

Table V: Observation Table for TOC test

Tank Height(m)	TOC(ppm)
0.5	651.2
1.0	598.3
1.5	580.9
2.0	560.5
2.5	565.3
3.0	612.7

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