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Process modelling and simulation of a Simple Water Treatment Plant

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Abstract: Water treatment plants are likely to experience problems such as the water level both in the filter cells and in the tanks tend to fluctuate widely. These create the potential for partial drainage, overflow, and potential initial turbidity breakthrough at the beginning of the filtration cycles. This paper presents a mathematical model for studying the process behavior of a water treatment plant. A state equation was developed as a mathematical model of the process. This mathematical model was used to simulate the effects of varying the parameters of the plant (R, C, and I) representing the restriction of the connecting pipes, the capacity of the tanks and the filteration of the water filter, respectively, on the state variables (height of tank, h, and flowrate, q). The results of the simulation are presented graphically in the study. From the analyses, it was observed that varying any of the values of the parameters of the model has an effect on the water levels in the various tanks and the flow of water through the filter. The analyses of this paper on modeling a water treatment plant is a very simple way of knowing from the beginning the various sizes of pipes, tanks and filter to be used and how these will affect the flow of water in the plant before going into the physical construction of the plant.

Keywords: *Water, State equation, Process Control, Modelling, Simulation, Filtration.*

1. Introduction

In everyday life we encounter many interesting but complex processes, and we want to be able to describe these processes in an understandable way [1]. This means that we want to describe some aspects of a real-world object, the process, in an abstract way. For instance, the problem formulation of this study is on a simple water treatment plant. Water treatment plants are likely to experience problems such as the water level both in the filter cells and in the tanks tend to fluctuate widely. These create the potential for partial drainage, overflow, and potential initial turbidity breakthrough at the beginning of the filtration cycles. These problems can be solved with process control modeling. Therefore, the construction of the model requires a thorough understanding of the process under study and, additionally, of modeling techniques [1].

1.1. Water

Water is one of the prime natural resources, an essential commodity for the living systems that constitute the biosphere [2], unique in its properties – the only substance to exist in all three phases, solid, liquid and gaseous, within the temperature range of the natural environment, continually renewed by the natural hydrological cycle of evaporation, vapour transportation and precipitation. Water conservation opportunities arise in increased efficiency through improvements in flow rates, pressure, temperature, chemistry, filtration or timing [3]. Metering both inflow and outflow from the system provides the operator information to determine if the system is meeting design efficiencies. Process control is often an area where increased efficiency can be obtained. Many operations can also increase efficiency by recirculating water or by filtering contaminants and reclaiming water for reuse internally. Thus the engineering associated with water resources management and use is multi-faceted.

This treatise deals with the technologies used to control the treatment process and its related use in industrial manufactures. It deals with the range of treatment processes used in the production of drinking and other high quality waters. In general, the presentation of the subject matter proceeds sequentially from basic principles through analytical/experimental methods to the development of process design methodologies. Processes are treated as unit operations, emphasizing those process fundamentals which can be applied to all process applications.

1.2. Modeling / Identification on water Treatment Plants

A model is a "simplified representation of a system (or process or theory) intended to enhance our ability to understand, predict, and possibly control the behaviour of the system" [4]. Modeling is grasping the central issues from reality and translating it into an abstract language such as a mathematical model. This kind of abstraction from reality is a fundamental characteristic of Science and Engineering and it allows us to grasp the essentials from a turbulent and sometimes chaotic world. Modeling is an essential part of all kinds of intellectual activities and enables us to understand, at least partially, reality [5]. A model is the way we want to describe the salient features of the system under study and that the model must possess some representation of the objects in the system and reflect the activities under which these entities act [6]. So, through [6] definition and [5] contribution, we can see that a model is actually a reflection of the modeler's understanding of reality, its components and their interrelations, described in a relatively simple, yet accurate enough to serve his purpose. Therefore, we will build a model of how we think the process will perform and calculate control limits for the expected measurements of the output of the process. Then we collect data from the process and compare the data to the control limits. By making certain assumptions it may be possible to write down governing equations for the system, in which case the equipment could be tested practically to confirm the form of the theoretically obtained dynamic relationship, and to confirm or determine the

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parameter values for this model. To select the best data for modelling, a thorough analysis of the data must be performed. For each potential input or output parameter, the data accuracy and frequency is ascertained [7]. The modelling of water treatment processes is challenging because of its complexity, nonlinearity, and numerous contributory variables [8]. In general, modeling is a process that aims to represent the dynamic behavior of a system. A derivation on physical behavior of system is commonly being considered. No doubt, it offers interesting characteristics of the system but it is significantly difficult and time consuming when dealing with large systems [9]. Water treatment plants are strongly known with the complexity of the model structures and the large number of states and parameters. Due to complexity factors, alternative modeling and identification approaches were explored. An optimal operation of a water treatment plant requires, as first step, the understanding of the flow behavior along the treatment facility [10]. Linear and nonlinear modelling methods are used here to model water treatment process, using both laboratory and process data as input variables. The approach involves variable selection to find the most important factors affecting the process parameters. This data analysis procedure seems to provide an efficient means of modeling the water treatment process and defining its most essential variables. Finally, the Computer simulations of subprocesses have been utilised for evaluating and testing ideas [11].

1.3. Interconnection of System elements in water treatment plant

To develop a model of the dynamics of a process, one needs to identify the flow paths and storage compartments of mass and to describe quantitatively how these paths and compartments are connected. Water from the storage tank flows into the treatment plant (sand and carbon tank), from the treatment plant down to ultraviolet triple water purification system into a cylinder where water is being collected through an outflow pipe.
The figure 1.1 below shows the physical setup with all the various regulating devices and it is pertinent to consider their relationship during the normal working of the plant.

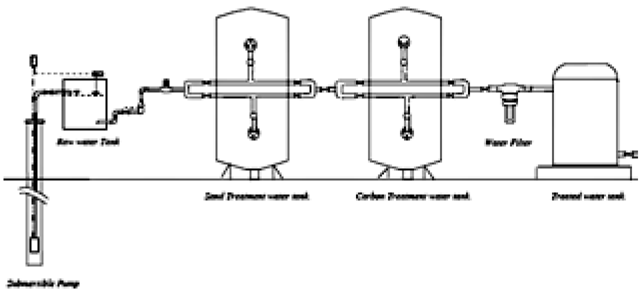

Fig 1.1. Flow sheet of a Simple water treatment plant.

The process control of a water treatment plant contains more than one process element. Therefore, appropriate resistance relation are needed to couple the resulting equations of conservation of mass to each element to give us simple mathematical relationships (models) which describe these observed phenomena of flow circuit. The diagram of figure 1.1 however shows the physical arrangement, how the system components function and it forms the basis for an analytical study. This also enables the production of a sketched diagram of the form shown Fig. 1.2.

The input liquid flow rate is labeled $q_i(t)$ and the controlled/output variables, or system response, will be assumed to be the liquid levels in the three tanks, designated $h_1(t), h_2(t)$ and $h_3(t)$, and flow rate through the filter, designated $q_1(t)$. The interconnecting and outlet pipes are assumed to have a linear level-flow relationship, so that the flow through each constriction is related to the liquid level difference across the constriction by the relationship,

$$q(t) = \frac{\Delta h(t)}{R} \qquad (1.1)$$

where,
$\Delta h(t)$ is the liquid level difference and the constant R is the linear flow resistance.

The rate of change of fluid volume within a tank can be described by,

$$a\frac{dh}{dt} \qquad (1.2)$$

where,
a is the cross-sectional area of a tank. For each tank a flow continuity equation can be written in which the rate of change of fluid volume is equated to the rate of inflow of fluid.

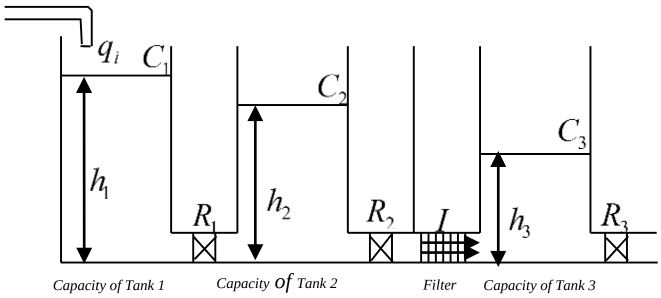

Figure 1.2. Coupled tank flow System.

A performance analysis of this process control would normally focus on the Rate of water flow (q) through, and the water-Level (h).
In this study, differential equations were used to model the dynamic process of water treatment plant based on the following assumptions:

1. Pressure differences at various stages of the process (water flow), which implies an adoption of a positive-flow direction through the Interconnected elements.
2. The input flow is equal to output flow if and only if the water level at each stage (capacitance) in the plant remains constant, which agrees with the law of conservation of mass.
3. Fluid's density remains constant despite changes in the fluid pressure (Model fluid behaviour as incompressible).
4. Laminar flow exists (the model for the tank height is linear).
5. The walls of the treatment tank and the reservoir are rigid.

1.4. Formulation of the model

The essence of formulating a model for this type of study is to enable one study the process theory beyond the limiting experimental values and even to prescribe the optimal conditions of the flow process without really having to embark upon endless practical experimentations [12]. Based on the assumption that the inflow minus outflow during the small time interval dt is equal to the additional amount stored in the tank, we see that

$$c\frac{dh}{dt} = q_i - q_0 \qquad \ldots\ldots\ldots\ldots \qquad \ldots\ldots\ldots\ldots (1.3)$$

where

$\frac{dh}{dt}$ is the dependent variable reflecting the system's behaviour, C is a parameter representing a property of the system, and $q_i - q_o$ represents the independent variable along which the system's behaviour is being determined.

From the definition of resistance, the relationship between q_0 and h is given by $q_0 = \frac{h}{R}$. This is a model that relates water flow rate to the height of water in each tank in the plant. For each tank a flow continuity equation can be written in which the rate of change of fluid volume is equated to the rate of inflow of fluid. The model generally starts as an analytical model, i.e. a set of differential equations [1].

The differential equations governing the behaviour of the network are:

$$C_1 \frac{d(h_1)}{dt} = q_i - \left(\frac{h_1 - h_2}{R_1}\right) \quad \text{.............................. (1.4)}$$

$$C_2 \frac{d(h_2)}{dt} = \left(\frac{h_1 - h_2}{R_1}\right) - q_1 \quad \text{.............................. (1.5)}$$

$$I \frac{d(q_1)}{dt} = \frac{I}{R_2}\frac{d(h_2)}{dt} + h_2 - h_3 \quad \text{.......................... (1.6)}$$

$$C_3 \frac{d(h_3)}{dt} = \frac{I}{R_2}\frac{d(h_2)}{dt} + h_2 - \frac{h_3}{R_3} \quad \text{........................ (1.7)}$$

Rearranging the equations, we have:

From equation (1.4)

$$C_1 \frac{d(h_1)}{dt} = q_i - \left(\frac{h_1 - h_2}{R_1}\right)$$

$$C_1 \frac{d(h_1)}{dt} = q_i - \frac{(h_1 - h_2)}{R_1}$$

$$C_1 \frac{d(h_1)}{dt} = \frac{q_i R_1 - h_1 + h_2}{R_1}$$

$$R_1 C_1 \frac{d(h_1)}{dt} = q_i R_1 - h_1 + h_2$$

$$\frac{d(h_1)}{dt} = \frac{q_i R_1}{R_1 C_1} - \frac{h_1}{R_1 C_1} + \frac{h_2}{R_1 C_1}$$

$$\frac{d(h_1)}{dt} = \frac{q_i}{C_1} - \frac{h_1}{R_1 C_1} + \frac{h_2}{R_1 C_1}$$

$$\frac{d(h_1)}{dt} = -\frac{h_1}{R_1 C_1} + \frac{h_2}{R_1 C_1} + \frac{q_i}{C_1} \quad \text{.............. .... (1.8)}$$

From equation (1.5)

$$C_2 \frac{d(h_2)}{dt} = \left(\frac{h_1 - h_2}{R_1}\right) - q_1$$

$$C_2 \frac{d(h_2)}{dt} = \frac{(h_1 - h_2)}{R_1} - q_1$$

$$C_2 \frac{d(h_2)}{dt} = \frac{h_1 - h_2 - R_1 q_1}{R_1}$$

$$R_1 C_2 \frac{d(h_2)}{dt} = h_1 - h_2 - R_1 q_1$$

$$\frac{d(h_2)}{dt} = \frac{h_1}{R_1 C_2} - \frac{h_2}{R_1 C_2} - \frac{R_1 q_1}{R_1 C_2}$$

$$\frac{d(h_2)}{dt} = \frac{h_1}{R_1 C_2} - \frac{h_2}{R_1 C_2} - \frac{q_1}{C_2} \quad \text{... .... (1.9)}$$

From equation (1.6),

$$I \frac{d(q_1)}{dt} = \frac{I}{R_2}\frac{d(h_2)}{dt} + h_2 - h_3$$

Substituting $\frac{d(h_2)}{dt}$ in equation (1.9), we have,

$$I \frac{d(q_1)}{dt} = \frac{I}{R_2}\left(\frac{h_1}{R_1 C_2} - \frac{h_2}{R_1 C_2} - \frac{q_1}{C_2}\right) + h_2 - h_3$$

$$I \frac{d(q_1)}{dt} = \frac{I h_1}{R_1 R_2 C_2} - \frac{I h_2}{R_1 R_2 C_2} - \frac{I q_1}{R_2 C_2} + h_2 - h_3$$

$$I \frac{d(q_1)}{dt} = \frac{I h_1 - I h_2 - R_1 I q_1 + R_1 R_2 C_2 h_2 - R_1 R_2 C_2 h_3}{R_1 R_2 C_2}$$

$$\frac{d(q_1)}{dt} = \frac{I h_1 - I h_2 - R_1 I q_1 + R_1 R_2 C_2 h_2 - R_1 R_2 C_2 h_3}{R_1 R_2 C_2 I}$$

$$\frac{d(q_1)}{dt} = \frac{I h_1 - I h_2 + R_1 R_2 C_2 h_2 - R_1 I q_1 - R_1 R_2 C_2 h_3}{R_1 R_2 C_2 I}$$

$$\frac{d(q_1)}{dt} = \frac{I h_1 - (I - R_1 R_2 C_2) h_2 - R_1 I q_1 - R_1 R_2 C_2 h_3}{R_1 R_2 C_2 I}$$

$$R_1 R_2 C_2 I \frac{d(q_1)}{dt} = I h_1 - (I - R_1 R_2 C_2) h_2 - R_1 I q_1 - R_1 R_2 C_2 h_3$$

$$\frac{d(q_1)}{dt} = \frac{I h_1}{R_1 R_2 C_2 I} - \frac{(I - R_1 R_2 C_2) h_2}{R_1 R_2 C_2 I} - \frac{R_1 I q_1}{R_1 R_2 C_2 I} - \frac{R_1 R_2 C_2 h_3}{R_1 R_2 C_2 I}$$

$$\frac{d(q_1)}{dt} = \frac{h_1}{R_1 R_2 C_2} - \frac{(I - R_1 R_2 C_2) h_2}{R_1 R_2 C_2 I} - \frac{q_1}{R_2 C_2} - \frac{h_3}{I} \quad \text{... . (1.10)}$$

From equation (1.7)

$$C_3 \frac{d(h_3)}{dt} = \frac{I}{R_2}\frac{d(h_2)}{dt} + h_2 - \frac{h_3}{R_3}$$

Substituting $\frac{d(h_2)}{dt}$ in equation (1.9), we have,

$$C_3 \frac{d(h_3)}{dt} = \frac{I}{R_2}\left(\frac{h_1}{R_1 C_2} - \frac{h_2}{R_1 C_2} - \frac{q_1}{C_2}\right) + h_2 - \frac{h_3}{R_3}$$

$$C_3 \frac{d(h_3)}{dt} = \frac{I h_1}{R_1 R_2 C_2} - \frac{I h_2}{R_1 R_2 C_2} - \frac{I q_1}{R_2 C_2} + h_2 - \frac{h_3}{R_3}$$

$$C_3 \frac{d(h_3)}{dt} = \frac{R_3 I h_1 - R_3 I h_2 - R_1 R_3 I q_1 + R_1 R_2 R_3 C_2 h_2 - R_1 R_2 C_2 h_3}{R_1 R_2 R_3 C_2}$$

$$\frac{d(h_3)}{dt} = \frac{R_3 I h_1 - R_3 I h_2 - R_1 R_3 I q_1 + R_1 R_2 R_3 C_2 h_2 - R_1 R_2 C_2 h_3}{R_1 R_2 R_3 C_2 C_3}$$

$$\frac{d(h_3)}{dt} = \frac{R_3 I h_1 - R_3 I h_2 + R_1 R_2 R_3 C_2 h_2 - R_1 R_3 I q_1 - R_1 R_2 C_2 h_3}{R_1 R_2 R_3 C_2 C_3}$$

$$\frac{d(h_3)}{dt} = \frac{R_3 I h_1 - R_3 I h_2 + R_1 R_2 R_3 C_2 h_2 - R_1 R_3 I q_1 - R_1 R_2 C_2 h_3}{R_1 R_2 R_3 C_2 C_3}$$

$$\frac{d(h_3)}{dt} = \frac{R_3 I h_1 - R_3 (I - R_1 R_2 C_2) h_2 - R_1 R_3 I q_1 - R_1 R_2 C_2 h_3}{R_1 R_2 R_3 C_2 C_3}$$

$$\frac{d(h_3)}{dt}=\frac{R_3 I h_1}{R_1R_2R_3C_2C_3}-\frac{R_3(I-R_1R_2C_2)h_2}{R_1R_2R_3C_2C_3}-\frac{R_1R_3Iq_1}{R_1R_2R_3C_2C_3}-\frac{R_1R_2C_2h_3}{R_1R_2R_3C_2C_3}$$

$$\frac{d(h_3)}{dt}=\frac{Ih_1}{R_1R_2C_2C_3}-\frac{(I-R_1R_2C_2)h_2}{R_1R_2C_2C_3}-\frac{Iq_1}{R_2C_2C_3}-\frac{h_3}{R_3C_3} \quad \ldots(1.11)$$

The resulting state equations are given by:

$$\begin{cases}\frac{d(h_1)}{dt}=-\frac{h_1}{R_1C_1}+\frac{h_2}{R_1C_1}+\frac{q_i}{C_1}\\ \frac{d(h_2)}{dt}=\frac{h_1}{R_1C_2}-\frac{h_2}{R_1C_2}-\frac{q_1}{C_2}\\ \frac{d(q_1)}{dt}=\frac{h_1}{R_1R_2C_2}-\frac{(I-R_1R_2C_2)h_2}{R_1R_2C_2I}-\frac{q_1}{R_2C_2}-\frac{h_3}{I}\\ \frac{d(h_3)}{dt}=\frac{Ih_1}{R_1R_2C_2C_3}-\frac{(I-R_1R_2C_2)h_2}{R_1R_2C_2C_3}-\frac{Iq_1}{R_2C_2C_3}-\frac{h_3}{R_3C_3}\end{cases} \quad \ldots(1.12)$$

The state equation's equivalent in x form is thus:

$$\begin{cases}\dot{x}_1=-\frac{x_1}{R_1C_1}+\frac{x_2}{R_1C_1}+\frac{u}{C_1}\\ \dot{x}_2=\frac{x_1}{R_1C_2}-\frac{x_2}{R_1C_2}-\frac{x_3}{C_2}\\ \dot{x}_3=\frac{x_1}{R_1R_2C_2}-\frac{(I-R_1R_2C_2)x_2}{R_1R_2C_2I}-\frac{x_3}{R_2C_2}-\frac{x_4}{I}\\ \dot{x}_4=\frac{Ix_1}{R_1R_2C_2C_3}-\frac{(I-R_1R_2C_2)x_2}{R_1R_2C_2C_3}-\frac{Ix_3}{R_2C_2C_3}-\frac{x_4}{R_3C_3}\end{cases} \quad (1.13)$$

In vector-matrix form, we have the process control equation as:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\end{bmatrix}=\begin{bmatrix}-\frac{1}{R_1C_1} & \frac{1}{R_1C_1} & 0 & 0\\ \frac{1}{R_1C_2} & -\frac{1}{R_1C_2} & -\frac{1}{C_2} & 0\\ \frac{1}{R_1R_2C_2} & -\frac{(I-R_1R_2C_2)}{R_1R_2C_2I} & -\frac{1}{R_2C_2} & -\frac{1}{I}\\ \frac{I}{R_1R_2C_2C_3} & -\frac{(I-R_1R_2C_2)}{R_1R_2C_2C_3} & -\frac{I}{R_2C_2C_3} & -\frac{1}{R_3C_3}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\end{bmatrix}+\begin{bmatrix}\frac{1}{C_1}\\ 0\\ 0\\ 0\end{bmatrix}[u] \quad (1.14)$$

The output equation is thus:

$$y=[0 \quad 0 \quad 0 \quad 1]\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\end{bmatrix} \quad \ldots\ldots \quad \ldots\ldots.. (1.15)$$

Where

$$\dot{x}=\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\end{bmatrix}$$

$$A=\begin{bmatrix}-\frac{1}{R_1C_1} & \frac{1}{R_1C_1} & 0 & 0\\ \frac{1}{R_1C_2} & -\frac{1}{R_1C_2} & -\frac{1}{C_2} & 0\\ \frac{1}{R_1R_2C_2} & -\frac{(I-R_1R_2C_2)}{R_1R_2C_2I} & -\frac{1}{R_2C_2} & -\frac{1}{I}\\ \frac{I}{R_1R_2C_2C_3} & -\frac{(I-R_1R_2C_2)}{R_1R_2C_2C_3} & -\frac{I}{R_2C_2C_3} & -\frac{1}{R_3C_3}\end{bmatrix};$$

$$x=\begin{bmatrix}x_1\\ x_2\\ x_3\\ x_4\end{bmatrix} \quad B=\begin{bmatrix}\frac{1}{C_1}\\ 0\\ 0\\ 0\end{bmatrix};$$

$$C=[0 \ 0 \ 0 \ 1]; \quad y=x;$$

x is the state vector while y is the response or output vector.

Where the variables are thus:

q_i = Water flow into the process.

q_o = Water flow from the process.

C_1 = Capacity of tank 1 (sand treatment tank).

C_2 = Capacity of tank 2 (carbon treatment tank).

I = filteration of the filter.

C_3 = Capacity of tank 3 (Treated water tank).

h_1 =Water level of tank 1.

h_2 =Water level of tank 2.

h_3 =Water level of tank 3.

q_1 =Rate of water flow through the filter.

R_1 = Restriction of pipe 1.

R_2 = Restriction of pipe 2.

R_3 = Restriction of pipe 3.

1.5. Model Simulation

Obtaining a model is never a goal in itself. There is always a purpose for obtaining a model. In many cases the purpose is process analysis and/or control design. In process analysis we want to predict the process behaviour in certain circumstances. Usually the analysis is done by simulation [13]. Model simulation is a program that is run on a computer separate from the system that is being designed. It is the representation of a rapidly changing or dynamic system developed in a form or design to simplify manipulation and study while using a computer for computation and analysis [14]. Table 1.1 shows the water treatment plant parameters used for the simulation. In order to study the dynamic behaviour of the process, the state-variable form of equation (1.14), were solved by incorporating the developed algorithm into the MATLAB m-file [15].

Simulation trials were conducted and the computed variables were picked and presented in this report. The variables (h_1, h_2, q_1, h_3) representing the responses (water levels) of individual sections of the process were plotted graphically.

Table 1.1. Water treatment plant parameters.

R_1	R_2	R_3	I	C_1	C_2	C_3
0.1	0.1	1.0	1.0	1e-03	1e-03	1000e-03
0.3	0.3	3.0	3.0	3e-03	3e-03	1300e-03
0.5	0.5	5.0	5.0	5e-03	5e-03	1500e-03
0.7	0.7	7.0	7.0	7e-03	7e-03	1700e-03
0.9	0.9	9.0	9.0	9e-03	9e-03	1900e-03

2. The Analyses of the Results of the Simulation

These analyses focuses on how the variation of the various parameters ($R_1, R_2, R_3, C_1, C_2, C_3$, I), representing the physical states of the various component parts (connections, tanks, filter) of the plant, influences the overall behaviour of the process, that is, the rate of flow of water into the sachet bags from the plant. The analysis of the results of the seven (7) simulations made by varying the values of the parameters of the model, one after the other, and the interpretations of the observed values of the rate of water flow variables (h_1, h_2, q_1, and h_3) are given below:

Legend for figures 1.3 – 1.37.

Data 1

h_1 = water level of tank 1.

Data 2

h_2 = water level of tank 2.

Data 3

q_1 = rate of water flow through the filter.

Data 4

h_3 = water level of tank 3.

Vertical Line

Ydot [m^3] =Response of water levels[m] and rate of water flow [cub-m/min] to change(s) in system parameters.

Horizontal Line

Time [sec] = (model time; real time).

2.1. First Simulation

An increase in the Restriction (R_1) to flow between tanks 1 and 2 (see plant), while keeping the other parameters constant, caused reasonable increase in the water level of tank 1, while water levels of tanks 2, 3 decreased and flow (q_1) through the filter (I) also decreased, as demonstrated by the graphs shown in figs 1.3, 1.4, 1.5, 1.6 and 1.7. In essence, this may be regarded as attempting to fine tune the process so as to influence the overall rate of water flow into the sachet bag (since varying R_1 has an effect on the water levels of tanks 1, 2, 3 and water flow (q_1) through the filter).

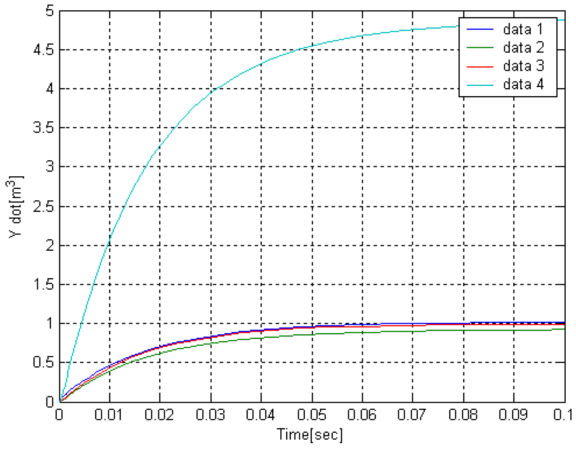

Fig 1.3. Effect of Restriction to flow on the Process, with R_1 =0.1

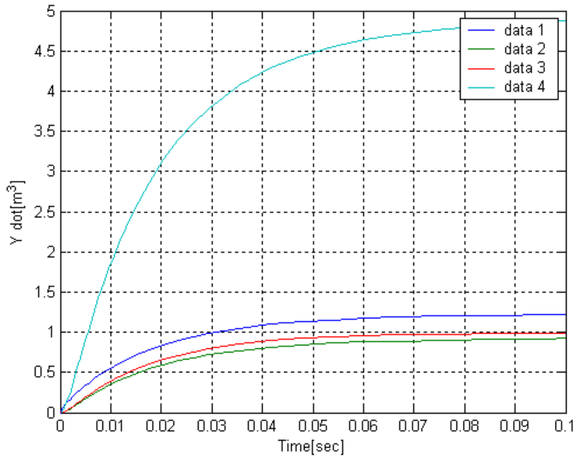

Fig 1.4. Effect of Restriction to flow on the Process, with R_1 =0.3

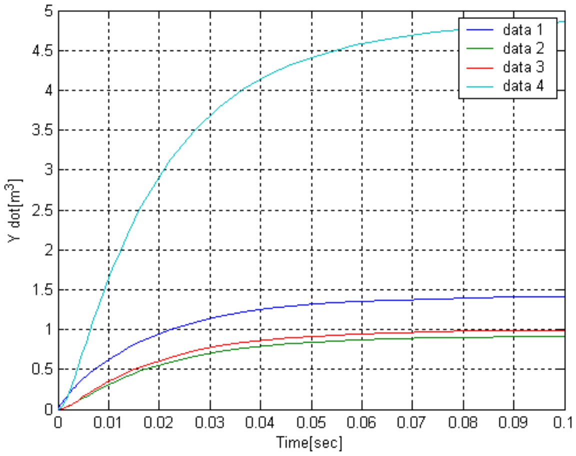

Fig 1.5. Effect of Restriction to flow on the Process, with R_1 =0.5

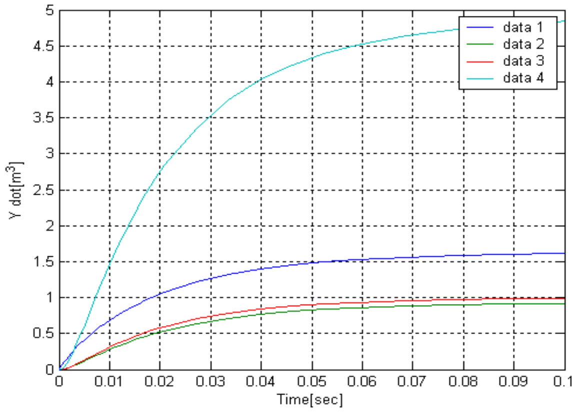

Fig 1.6. Effect of Restriction to flow on the Process, with R_1 =0.7

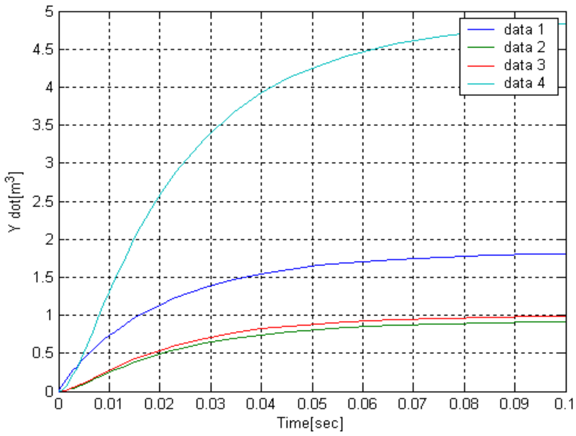

Fig 1.7. Effect of Restriction to flow on the Process, with R_1 =0.9

2.2. Second Simulation

An increase in the restriction (R_2) of water flow between tank 2 and filter (while keeping the other parameters constant) caused reasonable increase in water levels of tanks 1, 2, with tank 2 affected most, while the flow of water through the filter and the water level of tank 3 decreased. This could be interpreted as meaning that an increase in R_2 decreased the water levels in tank 3, thereby decreasing the water flow from the plant. These observations are demonstrated by the graphs shown in figs 1.8, 1.9, 1.10, 1.11 and 1.12. As stated above, this can also be interpreted as attempting to fine tune the process so as to influence the overall rate of water flow.

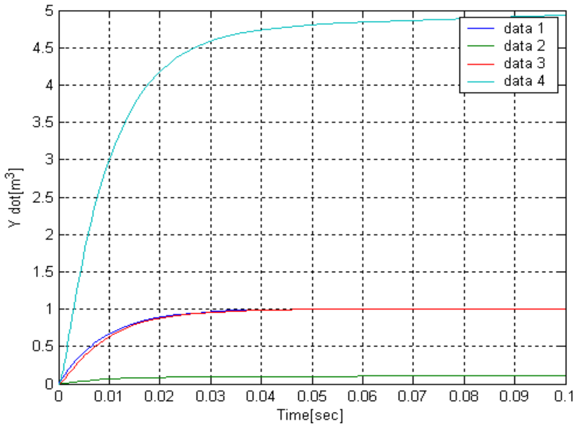

Fig 1.8. Effect of Restriction to flow on the Process, with R_2 =0.1

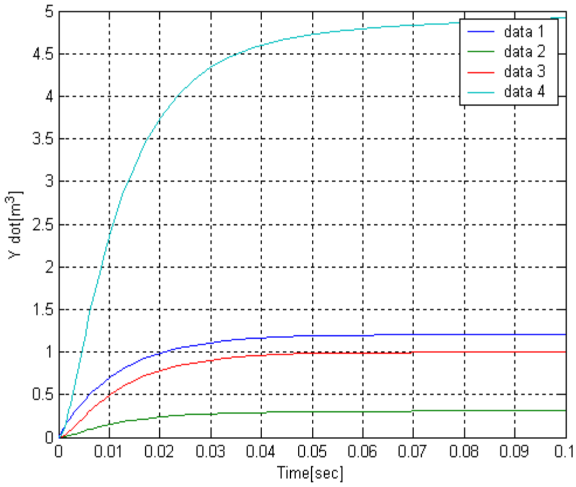

Fig 1.9. Effect of Restriction to flow on the Process, with R_2 =0.3

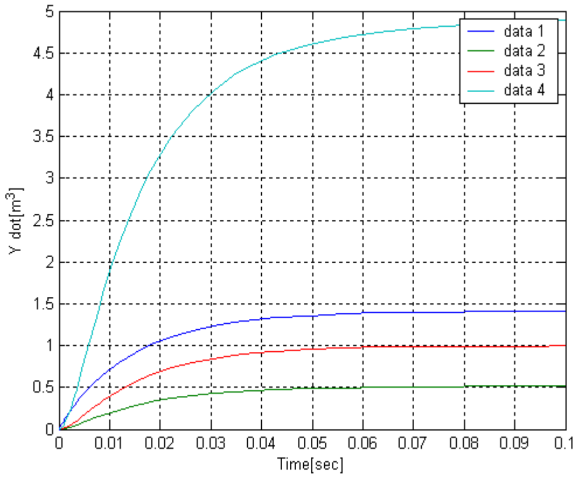

Fig 1.10. Effect of Restriction to flow on the Process, with R_2 =0.5

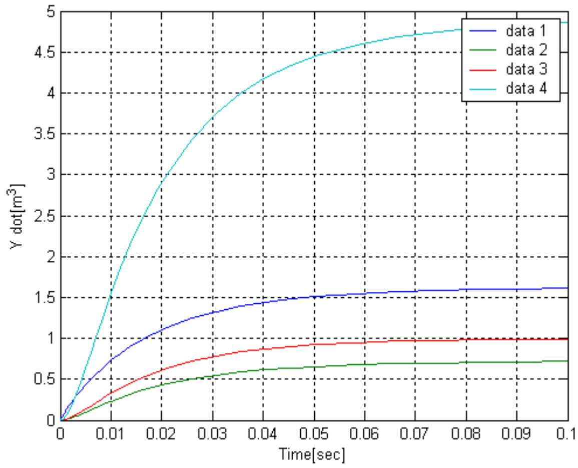

Fig 1.11. Effect of Restriction to flow on the Process, with R_2 =0.7

2.3. Third simulation

An increase in the restriction, (R_3) (while keeping the other parameters constant) caused an increase in the water levels of all the tanks 1, 2, 3 [minimal changes (increase) in water levels of tanks 1, 2 and reasonable changes (increase) in water level of tank 3], while flow of water through the filter decreased. This observation was demonstrated by the graphs shown in figs 1.13, 1.14, 1.15, 1.16 and 1.17. The essence of this is to fine tune the process so as to get the right flow of water from the plant. More specifically, this parameter is used to control the rate of water flow from the plant.

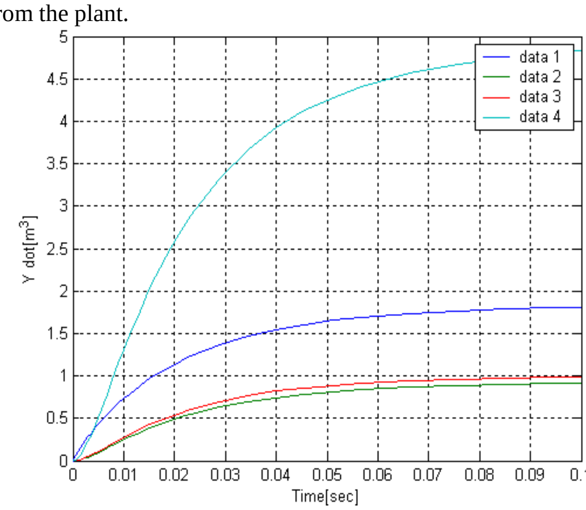

Fig 1.12. Effect of Restriction to flow on the Process, with R_2 0.9

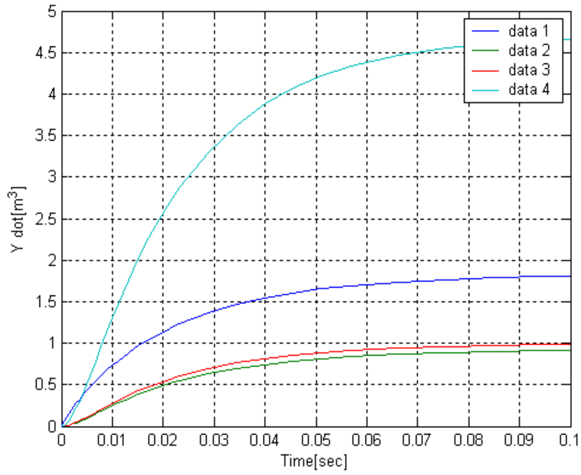

Fig 1.13. Effect of Restriction to flow on the Process, with R_3 =1.0

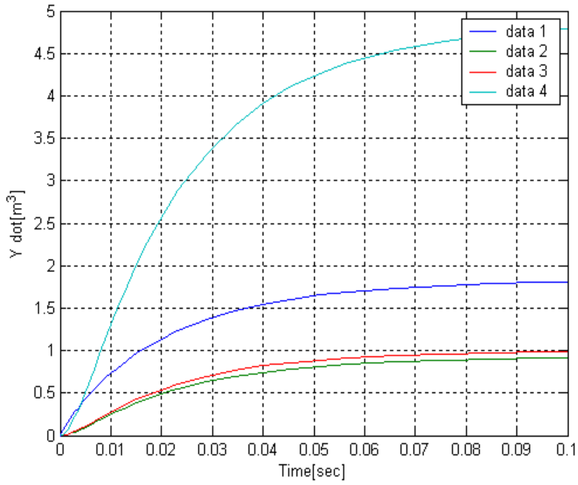

Fig 1.14. Effect of Restriction to flow on the Process, with R_3 =3.0

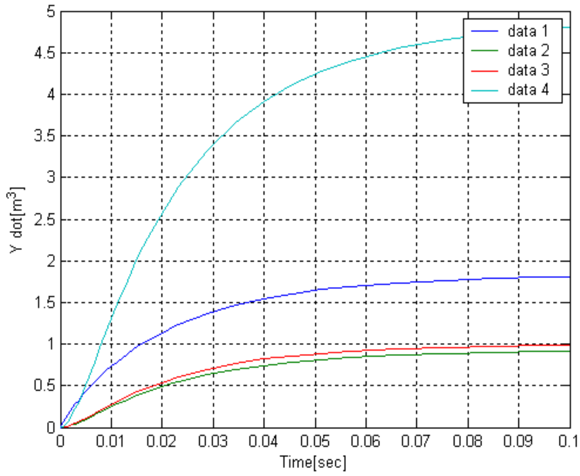

Fig 1.15. Effect of Restriction to flow on the Process, with R_3 =5.0

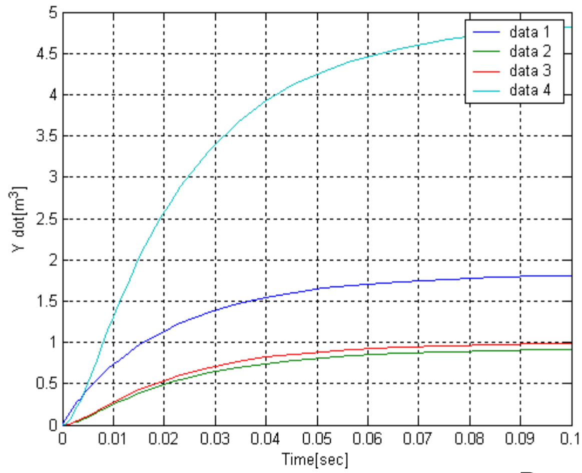

Fig 1.16. Effect of Restriction to flow on the Process, with R_3 =7.0

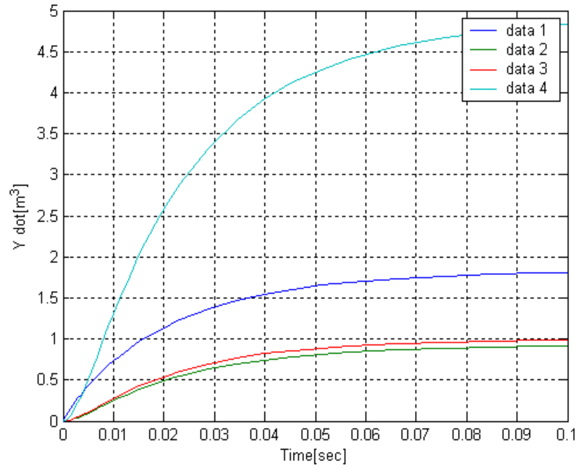

Fig 1.17. Effect of Restriction to flow on the Process, with R_3 =9.0

2.4. Fourth simulation

Here varying I (the inductance) and keeping other parameters constant caused minimal changes (increase) in the water levels of all the tanks 1, 2, 3, while the flow (q_1) of water through the filter decreased showing that at high filtration, the flow of water through the filter lessened (decreased).

This observation is demonstrated by the graphs shown in figs 1.18, 1.19, 1.20, 1.21 and 1.22. This could be interpreted as indicating that at high filtration (indicating increase in number of wound string of the conductor), the flow (q_1) of water through the filter decreases, thereby affecting the overall output of water flow.

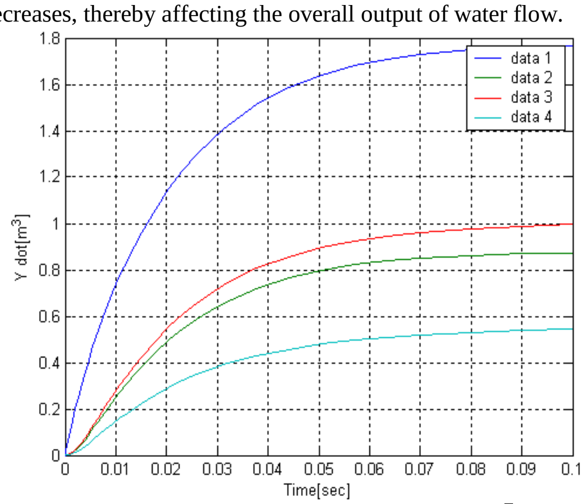

Fig 1.18. Effect of wound string on the Process, with L =1.0

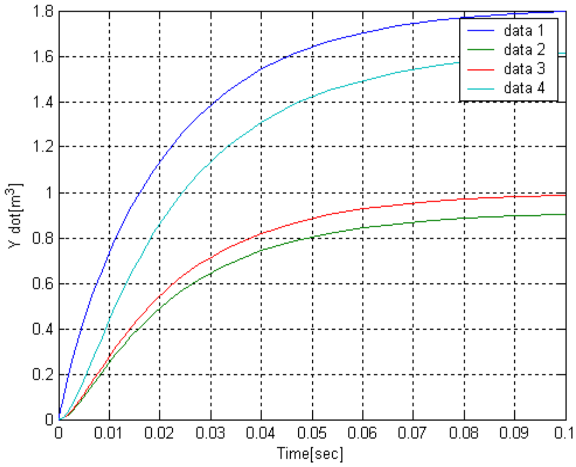

Fig 1.19. Effect of wound string on the Process, with L =3.0

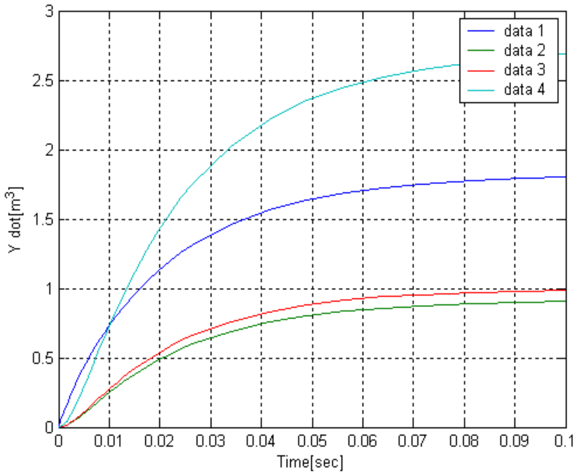

Fig 1.20. Effect of wound string on the Process, with L =5.0

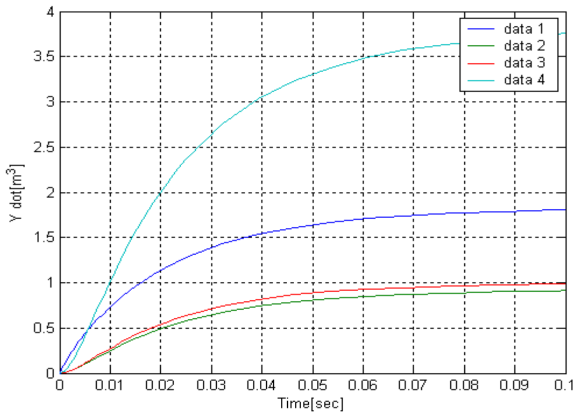

Fig 1.21. Effect of wound string on the Process, with L =7.0

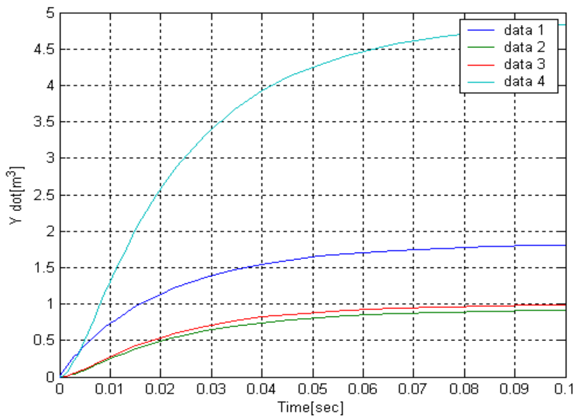

Fig 1.22. Effect of wound string on the Process, with L =9.0

2.5. Fifth simulation

Varying C_1 (increasing the capacity of tank 1) and keeping other parameters constant caused changes (decrease) in all the water levels of tanks 1, 2, 3 and flow (q_1) through the filter, as demonstrated by the graphs shown in figs 1.23, 1.24, 1.25, 1.26 and 1.27.

The essence of this variation is to study the effects of C_1 (capacity of tank 1) on the process (flow of water) and its interaction with the other parameters of the model. In this circumstance, the increase in the value of C_1 could be interpreted as decreasing the rate of water flow.

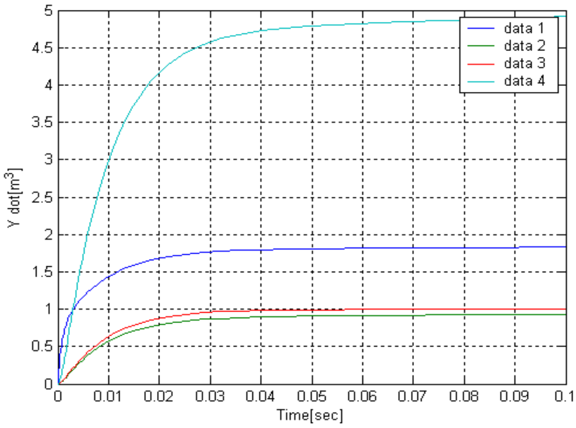

Fig 1.23. Effect of the Capacity of tank on the Process, with C_1 =1e-03

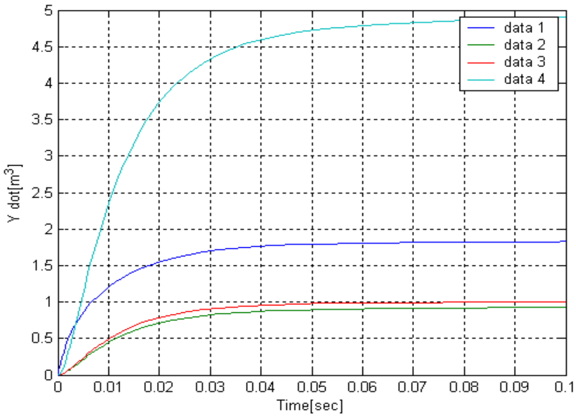

Fig 1.24: Effect of the Capacity of tank on the Process, with C_1 =3e-03

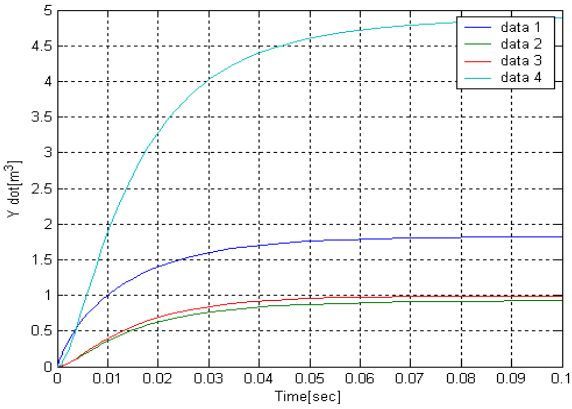

Fig 1.25: Effect of the Capacity of tank on the Process, with C_1 =5e-03

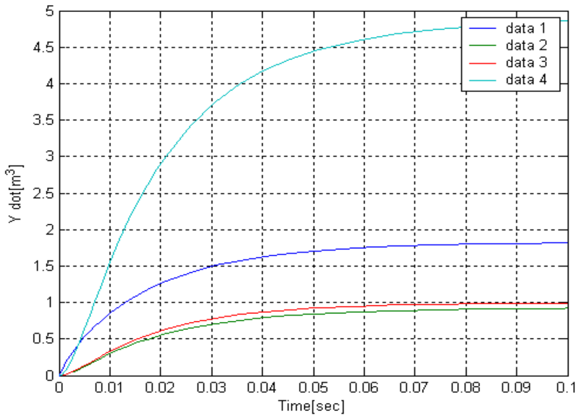

Fig 1.26: Effect of the Capacity of tank on the Process, with C_1 =7e-03

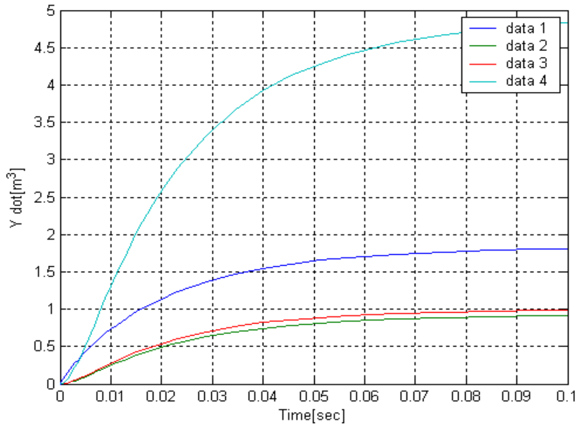

Fig 1.27. Effect of the Capacity of tank on the Process, with C_1 =9e-03

2.6. Sixth simulation

Varying C_2 (capacity of tank 2) and keeping other parameters constant caused changes (decrease) in all the water levels of tanks 1, 2, 3 and flow (q_1) through the filter, as demonstrated by the graphs shown in figs 1.28, 1.29, 1.30, 1.31 and 1.32. This is also to study the effects of C_2 (capacity of tank 2) on the process (flow of water) and its interaction with the other parameters of the model.

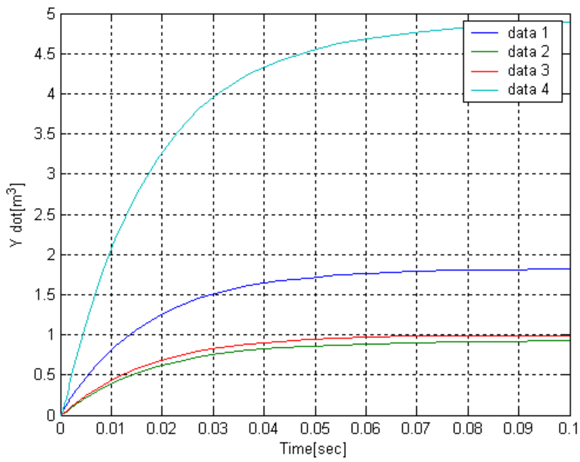

Fig 1.28. Effect of the Capacity of tank on the Process, with C_2 =1e-03

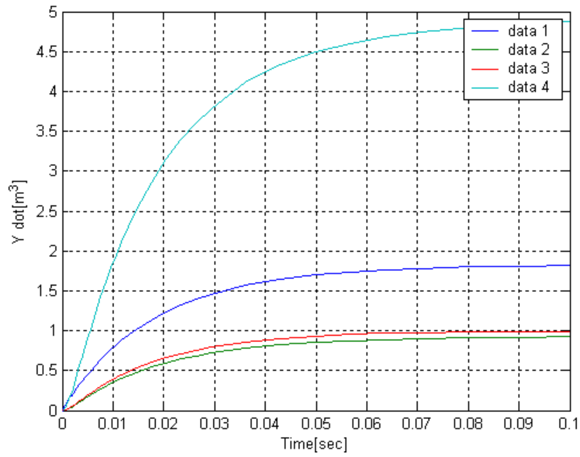

Fig 1.29. Effect of the Capacity of tank on the Process, with C_2 =3e-03

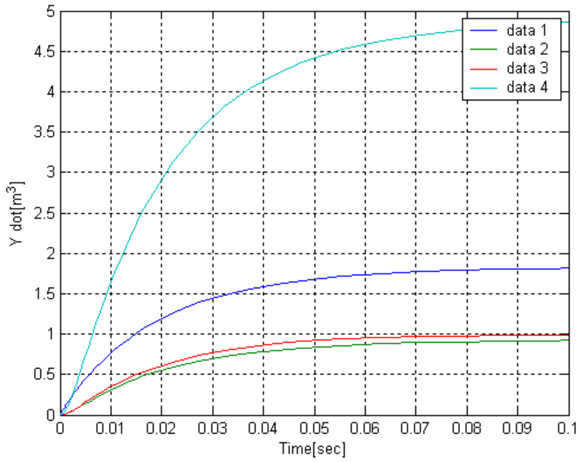

Fig 1.30. Effect of the Capacity of tank on the Process, with C_2 =5e-03

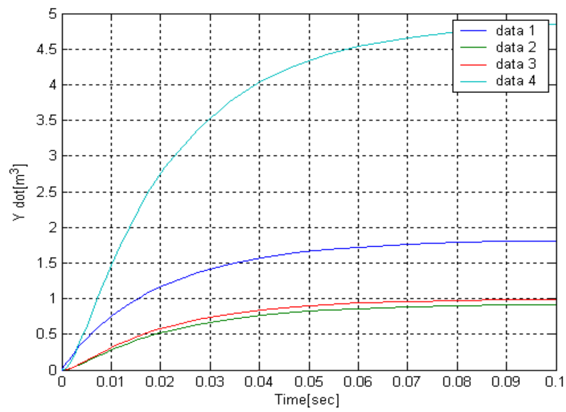

Fig 1.31. Effect of the Capacity of tank on the Process, with C_2 =7e-03

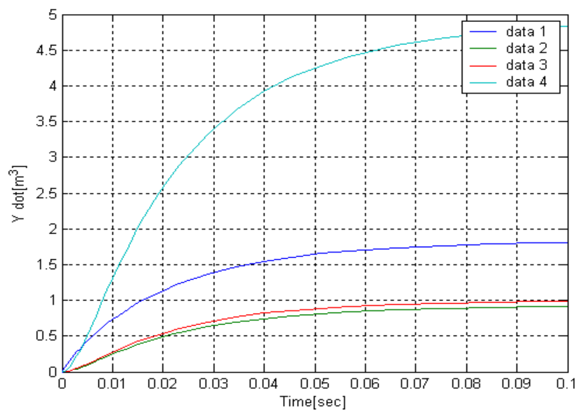

Fig 1.32. Effect of the Capacity of tank on the Process, with C_2 =9e-03

2.7. Seventh simulation

Varying C_3 (capacity of tank 3) and keeping other parameters constant caused changes (decrease) in all the water levels of tanks 1, 2, 3, while it caused an increase in flow (q_1) through the filter, showing that any variation of the capacity of tank 3 affects all the water levels of tanks 1, 2, 3 (decrease) and flow (q_1) of water through the filter (increase). This observation is demonstrated by the graphs shown in figs 1.33, 1.34, 1.35, 1.36 and 1.37. The essence of this variation is to study the effects of C_3 (capacity of tank 3) to the process (flow of water) and its interaction with other parameters of the model.

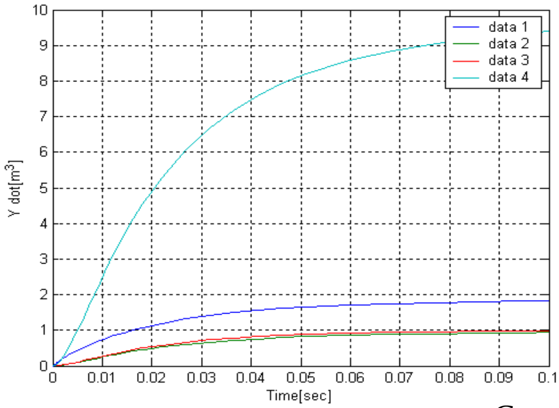

Fig 1.33. Effect of the Capacity of tank on the Process, with C_3 =1000e-03

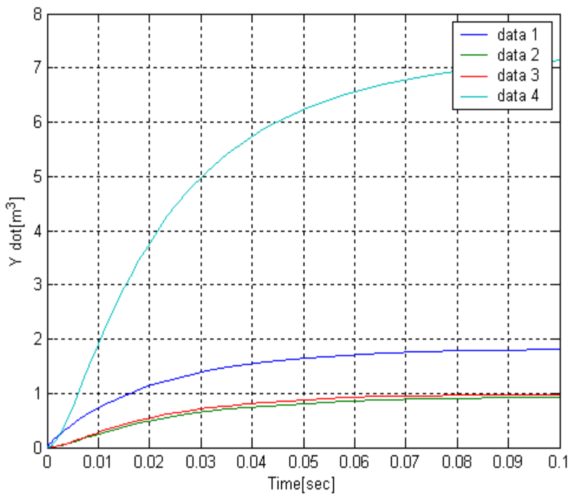

Fig 1.34. Effect of the Capacity of tank on the Process, with C_3 =1300e-03

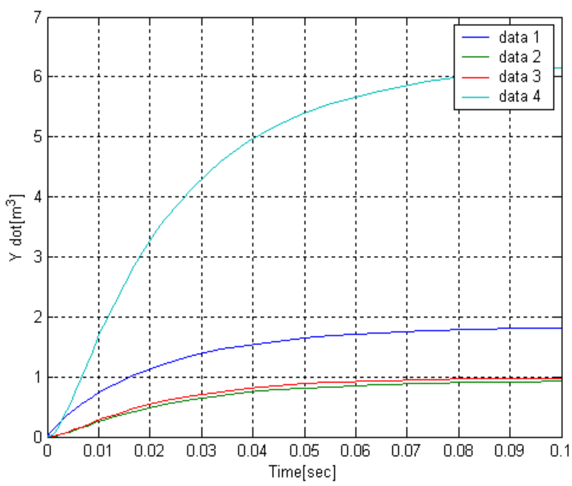

Fig 1.35. Effect of the Capacity of tank on the Process, with C_3 =1500e-03

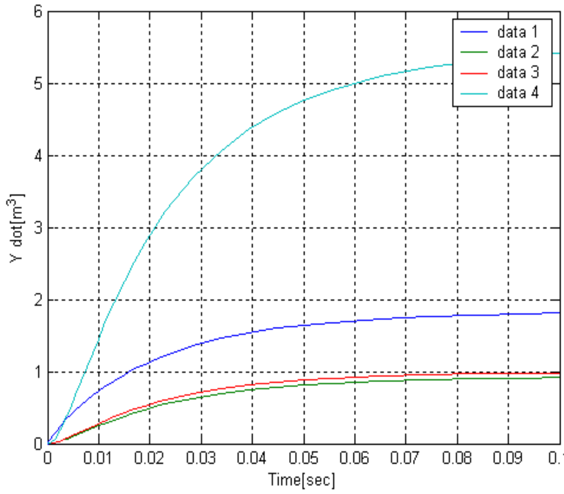

Fig 1.36. Effect of the Capacity of tank on the Process, with C_3 =1700e-03

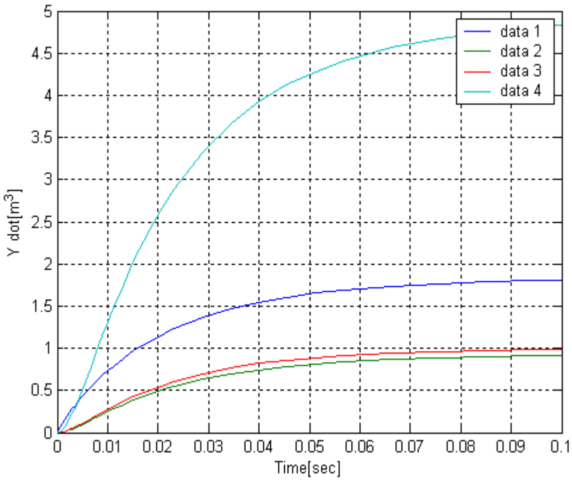

Fig 1.37. Effect of the Capacity of tank on the Process, with C_3 =1900e-03

3. Observation

3.1. The connecting pipes

It was observed that varying the restriction of the connecting pipes imply that either the radius (size) of the pipe is decreased/increased or the length of the pipe is increased/decreased which significantly influences the flow of water through the filter, but caused varying effects on the water levels in all the tanks. It is an attempt to fine tune the process so as to influence the rate of water flow (to get the right water flow from the plant).

3.2. The capacity of the tanks

It was observed that varying the value of the capacities of any of the tanks in the process significantly influences (decreases/increases) the water levels in all the tanks, but caused varying effects on the flow of water through the filter. This implies that an increase in the value of C (capacity of tank) decreases the water level (h) in the tank and hence the rate of water flow in the process, while a decrease in the value of C (capacity of tank) increases h and hence the rate of water flow in the process depending on the type and size of pipe used which must obey the relations stated in equations 1.4-1.7.

3.3. Inductance of the filter

It was observed that varying the inductance (I) of the filter influences the water levels in all the tanks, but caused changes (decrease) in the flow of water through the filter, implying that an increase in the inductance (I) (number of wound string on the filter cartridge) increases filteration. An increase in filteration tends to decrease the flow of water through the filter, and this in turn tends to influence the rate of water flow in the process.

4. Conclusions

The three major components of the plant; the connecting pipes, the water tanks and the filter have been modeled and the results of the simulation were presented graphically. From these results, it was observed that: varying the restriction of the connecting pipes significantly influences the flow of water through the filter, but caused varying effects on the water levels in all the tanks; varying the value of the capacities of any of the tanks in the process significantly influences the water levels in all the tanks, but caused varying effects on the flow of water through the filter; and varying the filteration (I) of the filter influences the water levels in all the tanks, but caused changes (decrease) in the flow of water through the filter.

From the analyses, it was observed that varying any of the values of the parameters of the model has an effect on the water levels in the various tanks and the flow of water through the filter. All these variations affect the overall rate of water flow through the treatment plant.

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