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Process Control Modelling and Simulation of a Water Plants Storage Compartments

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Abstract. A water plant is one out of numerous examples of critical infrastructure which include electric power systems, traffic control systems, manufacturing systems. Humans, domestic animals, industries, and to mention a few, rely so much on these critical infrastructures as they depend solely on water plants services. However, the present situation is such that water plant falls short of its use due to breakthdown, underperformance and lack of proper management in place, especially in Nigeria. This situation has hindered effective process control of water plants, thereby making it impossible to account correctly for its production process and to prevent break down of machinery. In this paper, we formulated, designed and evaluated a model that offers effective process control during production by a water plant. By means of a quantitative research approach, the study provided a full description of the flow paths and compartments connected in a process plant. We extracted information about the tanks sizes, piped diameter, number of pumps and number of tanks from the operational manual booklet of the water plants as the source of the dataset. A prototype model for the process plant was specified to establish the system's flow parts and storage compartments of mass. Based on the extracted data, we formulated mathematical models to describe the system's behaviour. The model was simulated in Simulink MatLab and used to investigate the effects of varying the parameters of the plant, especially the restriction (R) against water flow in the connecting pipes, as it affects the capacity of the tanks. The results of the simulation show that varying any of the values of the model parameters affects the water levels in the various tanks. Also, the results suggest a safe process parameter during processing. Notably, the result reveals that reducing the diameter of a pipe 1 from 300mm to 25mm or below will lead to water overflow in tanks, which will result in water wastage, machine and environmental damages. Thus, the research provided an effortless way of determining the various pipes sizes, sizes of tanks to be used and the expected output of the production process of the plant, before going into its physical production.

Keywords: process, modelling, simulation, water plant, storage.

1. Introduction

A water plant system falls under a category of systems known as critical infrastructures. Critical infrastructures include water management systems, electric power systems, traffic control systems and manufacturing systems [1]. They are known as critical infrastructures because they offer essential services to humans in today’s world. Just as a lot is dependent on electricity from production and manufacturing to transportation and communication, life itself depends on water, be it humans, animals or plants. They all need water for drinking, farming, production and so on. Nevertheless, electricity depends on water for its sourcing.

The importance of water cannot be overemphasized. Hence, the need to properly manage its production and distribution is crucial. Part of managing water production is ensuring that the production process is appropriately coordinated and controlled in order to achieve proper monitoring of the production process [2].

Achieving proper monitoring of a water plant production system can be achieved through building models that describe the system behaviour, hence a model is a representation of a physical object, a system, usually, a small version of it, which is intended to increase the ability to understand, predict and possibly control the behaviour of the system under consideration [3, 4, 5].

[3] observed that the primary purpose of formulating a model is to underscore the theory beyond limiting experimental values. Specifically, it provides support for determining the optimal conditions of the flow process without really having to embark on endless tedious practical experiments.

Building models of complex system have become necessary, this is because physical systems in industry involve continuous material flows; such as: liquid, gas or solid. Because of the operational complexities, it is difficult to reach definite analytical solutions [6]. Simulation is widely used for performance evaluation of the system's behaviour [7]. It is the imitation of the operation of a real process or system with a surrogate process or model. It provides feasibility to study complex systems [6]. The models for a simulation do not only provide quantitative information, but also increases the level of understanding of how the system works.

Since water supply systems are becoming more important, water demand has also increased rapidly in developing countries as a result of high population growth, improvement of living standards, rapid urbanization, industrialization and improvement of economic conditions, while accessible sources of water keep decreasing in number and capacity [8]. It has become needful to develop a process control model for a water plant– to effectively monitor, control and predict how to handle water from the point of production. Its production output in their storage compartments is to prevent waste of water as a result of poor management, and also to ensure the safety of the machines and its environment. And, it further simulates the system to investigate, and ensure safe process parameters to adopt during production.

The rest of the paper is organized as follows: Section 2 discusses the literature review, while section 3 describes the methodology. As section 4 presents the model implementation of the study, the discussion of the result is presented in section 5. Finally, section 6 concludes the paper and identifies areas for future research.

2. Related Works

According to [2], water is an essential element required for the sustenance of life. Demand for drinking water is increasing continually with a corresponding increase in population. This ever-increasing demand can be fulfilled by designing efficient water distribution networks based on advance computing systems. These systems include modern hydraulic modelling and designing of software-based solutions. In this regard, we have presented an extensive review of softwares used in designing water distribution networks and data management of hydraulic properties of networks in this section.

A review shows that modelling softwares have been considered as tools for managing water distribution which include public domain softwares like EPANET, Branch and Loop, as well as commercial softwares, like Aquis, WaterGEMS and WaterCAD [2]. These water distribution system designing softwares differ from each other in various aspects like their functionality, compatibility to different computational systems– graphical user interfaces (GUIs), searching and optimizing algorithms, languages and programs used in their developments [2]. These qualities about these softwares make it difficult to use generally, thus the need for a more generalized platform-based approach towards modelling the management of water systems. The paper submits that the choice of water distribution network software is based on the availability of the data, time, financial implications, resources, applicability and overall purview of the project. This paper focuses on the distribution of water to targeted destinations, and not focused on monitoring the storage compartments of water plants; this is the aim of this research work.

As observed in [9], modelling is increasingly being used in water resources and river basin management, primarily because of its enormous ability to store, analyze and display numerical and spatial data [9]. Experts– as well as researchers– have applied models and software products for simulation and solutions in a variety of commercial water projects and research studies over the years. This research further presents three successive modelling examples, developed by [9]; they include: an On-Farm irrigation case on Songwe irrigation scheme (Tanzania) using model SIRMOD-III; an "Irrigation Network Operation" on Rwimi River (Uganda) using CANALMAN; and the third was applying an irrigation network module (CropMatch), developed by WMRI, in "Tanta Navigation Canal" assessment. Moreover, in such cases, modelling of irrigation networks and eco-agricultural interventions became most effective to verify functionality, guess efficiencies, validate consistency, and to avoid design mistakes and environmental hazard [9]. Generally, it was concluded that:

1. Modelling was highly recommended to verify the best economic design for agro-irrigation projects enabling adequate farm sizing, channels and drains spacing for good irrigation and drainage duties, as well as avoiding relevant problems like deficit irrigation and waterlogging.

2. For the best modelling and analysis of an agro-ecological system, prior modelling selection and evaluation is worthwhile to permit a lesser modelling complexity; regarding the system boundaries and objectives: the physical, environmental and financial restrictions.

3. Modelling had supported design of network elements (components) as well as ensured good harmony of operation, efficient performance and water saving.

4. Modelling enabled examining water managing scenarios (such as applying internal water rotation), system maintenance, helped planning to conserve resources, and permitted maximizing efficiencies of water use and crop productivities.

Water sources like river basins are seen as major units of analysis aimed at addressing the challenges facing water management [9]. Modelling at this scale can provide essential aid for policy and decision-making on water management and water allocation [9].

Therefore, according to [10], a model was developed which aimed at simulating water flow with reliable parameters at the same time allowing the analysis of water consumption in identified areas of concern. This model was used to investigate daily domestic water consumption in County Sligo, Ireland. Water flow data were obtained in fifteen-minute intervals from bulk meters those identified areas of concern. The water consumption data were randomly selected at different time interval, and the average fitted into the model. In all cases, the parameters proved to be consistent ($\alpha=0.05$) and the correlation coefficients (r2) were high, hence demonstrating the validity of the approach. This research was aimed at investigating only the amount of water consumed, but failed to account for the management of this water at the point of production.

Other contributions include, a mathematical approach by [11]. This mathematical model was used to simulate a simple water filter in a controlled environment. The model revealed that varying the parameters of the plant such as restriction to water flow through the connecting pipes, the capacity of the tanks and the filtration by the water filters, had a direct effect on the outcome of the plant. This work failed to address the question of mass balance in a more complex facility, in this case a large water plant.

Also, in [12], the water distributin network in Tanta city, one of the major Egyptian cities was studied for the puprpose of optimizing its design and extension of its services due to the aging network and preventing future decongestion of the network, based on field data, the plant caliberations were done to determine the optimal design for improving its quantity of supply and quality preservation.

[13] adapts modelling of drinking water treatment processes within the Stimela environment, a modelling environment developed by Delft University of technology for water quality modelling. In this work, internet technology was used to access water quality data from online measurements to form the model calculation. This data aimed at being useful to operators in other locations in anaysing problems and proper management on weekly, monthly and yearly reports. This work presented yet another level of planning and projecting operations of a water treatment plant through data sharing but could not provide a quantitative measure of a water plant.

In another related approach by [14], MATLAB is used to show the application of computer software to solve real life engineering problems by simulating theoretical derivations in a set of governing equations. This application of MATLAB was used on mechanical engeeneering fluid mechanics to show best selection of pipes in series or parallel of different diameters, roughness and lengths to achieve best operational conditions for a pump in a specified pipe network. This paper attempted to offer a solution by ensuring that the right equipment is used during production.

3. Materials and Methods

We followed the quantitative research approach in this paper. However, the goal is to describe quantitatively the flow paths and compartments connected in a process plant for the GMWW. Thus, we developed a model for the process plant to establish the system's flow parts and storage compartments of mass. In this paper, we reported the design specification of the model; hence the prototype model is developed. Data were obtained from the operational manual booklet, information about the tanks sizes, piped diameter, number of pumps and number of tanks are extracted. Based on the available data from the plant, mathematical models are developed to describe the behaviour of the system.

3.1 Specifications of the Greater Makurdi Water Treatment Plant

The water treatment plant (WTP) consists of mechanical and chemical stages. Table 1 briefly describes the different stages of mechanical and chemical treatments.

Table 1: Different stages of Mechanical and Chemical Treatments

SN	Stages	Description
	Mechanical Stage	
1	Hydro-cyclones	The spinning effect of hydro-cyclones removes sand accompanied by water from the river pumps so as to avid sand from entering into the plants compartments.
2	Cascade aerator	Oxidation takes place as water flows down the cascades to reduce river water odour from water from the river.
3	Horizontal flow clarifiers	At this stage, newly created flocks settle at the bottom of the tank while clear water moves out for filtration.
4	Rapid gravity sand filtration	The water is filtered and made safe for consumption.
5	Clear Well tank (Storage Chamber)	This is the chamber where clean water is stored at the end of treatment.
	Chemical Stage	
1	Chemical coagulation chamber	Chemicals are added to enable particles form coagulants that can be extracted from the water.
2	Flocculation chamber	Polyelectrolytes are added to enable small coagulants to form very large flocks of solids for easy extraction from the water.

3.2 Prototype Model of Greater Makurdi Water Works Treatment Plant

The prototype model of the water plant in Figure 2 shows the water compartments. Water enters into the plant from the river, through the cascades, then flows into the water plant. Also, water moves through each of these compartments until the water is collected in the “clear well tank”. From the “clear well tank”, water is pumped out to beneficiaries.

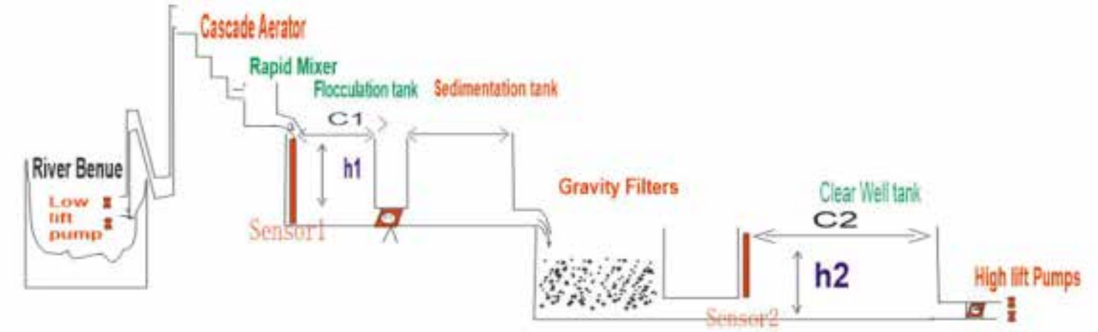

Fig. 1: Prototype model of the Plant.

3.3 Process Flow of the Greater Makurdi Water Treatment Plant

The process flow of the greater makurdi water work’s treatment plant as shown in Figure 1 starts at the Inlet Pumping Station / low lift pump station (LLPS). The inlet structure here is a concrete structure that includes the low lift pump station installed in river Benue. A pipeline of 1000mm conveys raw water from LLPS to the hydro cyclones and from there to the aeration cascades. At this stage, the discharge pipe from each pump of diameter 300mm leads water from the source to the hydro cyclones. There is constant monitoring of the river water level, which is done by an indicator transmitter. The reading of the water level is used for both indication and protection of the intake pumps from breakdown in the river. This is because, when the water level in the river is low, and the velocity is low, pumps in the low lift pump station can be changed. Otherwise, it is highly dangerous, attempting to remove or insert pumps when the water level in the river is high.

- **Hydro Cyclones**

The water from the low lift pumps flows through the hydro cyclones. This is where the de-sanding is done. Most of the sand which comes with the river water will be removed from the water here. Eight (8) hydro cyclones are responsible for this. Also, each of these hydro cyclones is designed for the treatment of 260m3h of water. In a situation where the plant has to operate on lower capacity, some of the hydro cyclones will have to be closed to maintain the above flow rate through each unit. That is because a lower water flow rate through a hydro-cyclone will reduce sand separation efficiency [15].

The sand removed from the water is accumulated at the bottom of each hydro-cyclone. It will be periodically flushed back to the river. Each of the hydro cyclones is connected to the main pipe of water from the LLPS by an inlet manual butterfly valve and to the outlet pipe by an outlet manual butterfly valve.

- **Cascade Aerator**

From the hydro-cyclones, the water moves to the cascade aerator where oxidation is performed by allowing water to pass through an array of cascades, thus creating small waterfalls with thin water layers.

- **Coagulation Chamber**

Water flows from the cascades to the coagulation chamber. In this chamber, coagulation takes place. Coagulation is performed by adding into the water chemicals, such as: alum and lime. This makes suspensions in the water to coagulate and create/form large flocks which can be removed by sedimentation and filtration. Mixing of the chemicals with raw water is performed in a well-mixed chamber where the residence time of the water is approximately 1.3 minute at a flow rate of 2100m3h. From the rapid mixer, the water flows by gravity to the flocculates. Table 2 shows the characteristics of the Coagulation Chamber.

Table 2: Characteristics of Coagulation Chamber

Coagulation (Rapid Mixer) Chamber	Units	Values
Flow rate	M3/h	2100
Residence time	Min	1.3
Tank volume	M3	45
Number of tanks	Units	1
Width	M	2.75
Length	M	4.95
Water depth	M	3.3
Specific power	w/m3	170
Power for mixer	Kw	7.5

- **Flocculation**

In this step, small suspended particles– which act under the influence of flocculating agents– coalesce and form large flocks. Polyelectrolytes are added to enhance flocculation. Water is expected to be resident here for about 20-30 minutes. From here, water flows by gravity into the clarifiers, and also known as sedimentation unit. Table 3.2 shows the characteristics of flocculation chamber.

- **Sedimentation (Clarifiers)**

In this stage, flocculated water flows into large tanks, which are designed for very slow velocities. This will allow newly-created flocks to settle down at the bottom of the tank while clear water flows out. The water from the clarifiers flows to the gravitational filters; the residence time of water in the clarifiers is about 90 minutes. Table 3.2 shows the characteristics of the sedimentation chamber.

- **Filters**

Filtration is performed by passing clarified water through a bed of sand of 1.0m deep. The sand used here is of particle sizes 0.6-0.9mm. The sand is placed directly on the filters under the drain to resist the flow of water. This water then flows to the clear well tank.

Table 3: Characteristics of the Flocculation Chamber

Flocculation Chamber	Units	Values
Flow rate	M3/h	2100
Residence time	Min	20
Total volume	M3	720
Tank volume	M3	45
Number of tanks	Units	2
Width	M	9.2
Length	M	9.2
Water depth	M	4.24
Specific power	w/m3	3
Power for mixer	Kw	1.1

Table 4: Characteristics of Sedimentation Chamber

Sedimentation (Clarifiers) Chamber	Units	Values
Flow rate	M3/h	525
Residence time	Min	90
Volume of water per one clarifier	M3	800
Tank volume	M3	45
Number of units	Units	4
Width	M	6
Length	M	36
Water depth	M	3.72
Specific power	w/m3	3
Area per one clarifier	Kw	1.1

- **Clear Well Tank**

The clear well tank receives water from the gravity filters. It has an outlet to the treated water pumping station known as the high lift pumping station and to the filters backwash pumping station. The clear water tank is a concrete rectangular tank with maximum water holding capacity of the tank which is approximately 5800m3 at the overflow level.

3.4 Mathematical Model Formulation of the Process Plant

3.4.1 Analysis of the Process Flow Model

From figure 1 above, the input flow rate is labelled $q_{i(t)}$, and the controlled/output variables of the system response will be assumed to be the liquid levels in the two tanks designated $h_1(t)$ and $h_2(t)$.

The interconnecting pipes and outlet pipes are assumed to have a linear level flow relationship so that the flow through each pipe is related to the liquid level difference across the tanks bearing in mind the resistance of the pipes on the water flow.

In investigating the volume of the tanks, we use the general equation for the volume of a solid which is given as;

Volume = Area of base x height of tank

$$\text{i.e } V = Ah \qquad (1)$$

Since the volume changes over time, equation 3.1 will be differentiated with respect to time, hence;

$$\frac{dv}{dt} = A\,\frac{dh}{dt} \qquad (2)$$

From equation 2 $\frac{dv}{dt}$ is the change in volume with respect to time, $\frac{dh}{dt}$ is the change in height of water level with respect to time while A is the Area which remains constant.

The change in volume of the liquid in a container is determined by the quantity of water flow into the container minus the quantity of water flow out of the container, this can be expressed as;

$$\frac{dv}{dt} = q_{in} - q_{out} \tag{3}$$

Hence; equation 2 becomes;

$$q_{in} - q_{out} = A\,\frac{dh}{dt} \tag{4}$$

In formulating this problem, the derived equations were used to model the dynamism of the water process based on the following assumptions;

Pressure difference exists at various stages of the process flow (water flow), this shows the adoption of a positive flow direction through interconnected pipes.

The input flow is equal to the output flow if and only if the water level at each stage in the plant (capacitance) remains constant, which agrees with the law of conservation of mass.

Fluid density remains constant despite changes in the fluid pressure which agrees with fluid behaviour as an incompressible fluid.

Also, laminar flow exists.

Lastly, the walls of the tanks and reservoir are rigid.

3.4.2 Process Model Formulation

According to [16], the inflow of water minus the outflow of water during the small time interval is equal to the additional amount of water stored in the tank, as expressed in equation 4;

$$q_{in} - q_{out} = A\,\frac{dh}{dt}$$

Hence, $\frac{dh}{dt}$ is the dependent variable showing the system's behaviour and A is a parameter representing the capacitance (C) of a tank, and $q_i - q_o$ represents the independent variable along which the system behaviour is investigated.

Water flow resistance from the tank is expressed as a relationship between q_{out} and h which is given by;

$$q_{out} = \frac{h}{R} \tag{5}$$

Equation 5 relates the water flow rate to the height of water in each tank in the plant. Hence for each tank, a flow continuity equation is expressed, where the rate of change of fluid volume is equal to the rate of inflow of fluid.

Based on [11], the model is built using a set of differential equations. The differential equations showing the behaviour of the system activities are;

Tank 1

$$C_1\frac{d(h_1)}{dt} = q_{in} - q_{out1} \tag{6}$$

But $q_{out1} = \frac{h_1-h_2}{R_1}$ (7)

Hence, equation 3.6 becomes;

$$C_1\frac{d(h_1)}{dt} = q_{in} - \frac{h_1-h_2}{R_1} \tag{8}$$

Tank 2

$$C_2\frac{d(h_2)}{dt} = q_{in} - q_{out2} \tag{9}$$

But q_{in} for Tank 2 $=q_{out1}$ of Tank 1 $=\frac{h_1-h_2}{R_1}$

While q_{out2} (in Tank 2) $=\frac{h_2}{R_2}$ (10)

Hence, equation 9 becomes:

$$C_2\frac{d(h_2)}{dt} = \frac{h_1-h_2}{R_1} - \frac{h_2}{R_2} \tag{11}$$

Rearranging the equations will give the following:

From equation (6)

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

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

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

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

$$\frac{d(h_1)}{dt} = \frac{1}{C_1}\left(q_{in} \; - \frac{h_1}{R_1} + \frac{h_2}{R_1}\right) \qquad (12)$$

From equation (11)

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

$$C_2 \frac{d(h_2)}{dt} = \frac{R_2(h_1 - h_{2)} - R_1 h_2}{R_1 R_2}$$

$$R_1 R_2 C_2 \frac{d(h_2)}{dt} = \; R_2(h_1 - h_{2)} - R_1 h_2$$

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

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

$$\frac{d(h_2)}{dt} = \frac{1}{C_2}\left(\frac{h_1 - h_2}{R_1} - \frac{h_2}{R_2}\right) \qquad (13)$$

q_i= water flow into the process, C_1= capacitance of tank 1, C_2= capacitance of tank 2
h_1= water level of tank 1, h_2= water level of tank 1, R_1= restriction of pipe 1, R_2= restriction of pipe 2

4. Results

To show the performance of the model, we simulate equations 12 and 13.

4.1 Model implementation

In this simulation, the set of equations 12 and 13 are modelled using Simulink/Matlab. The equations are;

$$\frac{d(h_1)}{dt} = \frac{1}{c_1}\left(q_1 - \frac{h_1 - h_2}{R_1}\right) \qquad (12)$$

$$\frac{d(h_2)}{dt} = \frac{1}{c_2}\left(\frac{h_2 - h_1}{R_2} - \frac{h_2}{R_2}\right) \qquad (13)$$

These equations describe the flow of water through tanks.

$\frac{d(h_1)}{dt}$ is represented as h.1 and

$\frac{d(h_2)}{dt}$ is represented as h.2

Hence, equations 12 and 13 becomes;

$$h.1 = \frac{1}{c_1}\left(q_1 - \frac{h_1 - h_2}{R_1}\right) \qquad (12)$$

$$q_{out1} = \frac{h_1 - h_2}{R_1} \qquad (7)$$

$$h.2 = \frac{1}{c_2}\left(\frac{h_2 - h_1}{R_2} - \frac{h_2}{R_2}\right) \qquad (13)$$

While q_{out2} (in Tank 2) = $\frac{h_2}{R_2}$ (10)

Therefore, we develop the prototype model shown in figure 1 in matlab Simulink using equations 12 and 13. The system takes in qi as input and investigates the water levels in tank 1 and tank 2.

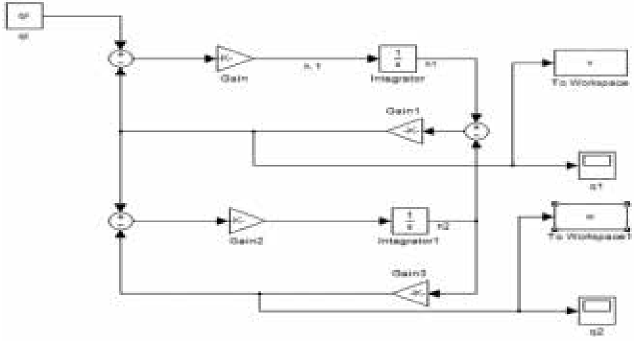

Fig. 2: Simulink structure showing the simulation of the system.

4.2 Model Prediction

In our model prediction, we investigate the water levels of the tanks by adjusting the diameter of the connecting pipes. In addition, we monitor the behaviour of the system bearing it in mind that the height of tank A1 is 4.24m while A2 is 2.73m.

Table 5: Simulation Parameters

Simulation S/N	R1(mm)	R2(mm)
First Simulation	300	300
Second Simulation	300	200
Third Simulation	300	100
Fourth Simulation	300	50
Fifth Simulation	300	25
Sixth Simulation	200	300
Seventh Simulation	100	300
Eigth Simulation	50	300
Ninth Simulation	25	300

4.3 Experiments

Differents experiments were conducted while varying the values of R1 and R2. The values are presented in Table 5.

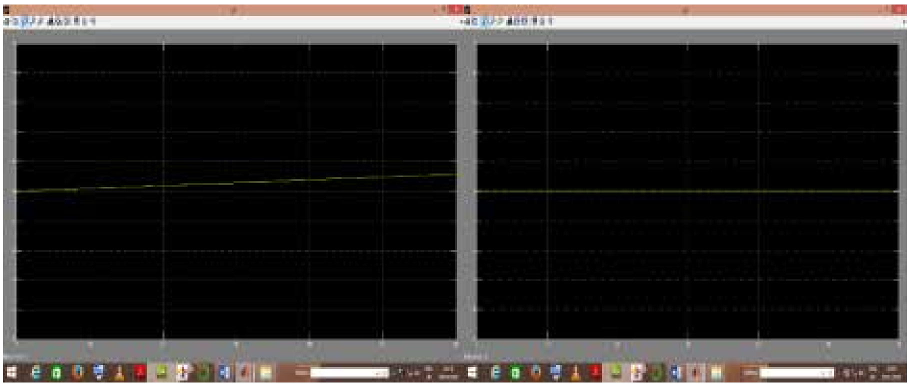

Fig. 3: First Simulation (R1=300 and R2 = 300).

5. Discussion

This section discusses the results of the simulation in section 4. The results from subsection 4.3.1 discussed under subsections 5.1.1 to 5.1.11, respectively, as presented below.

5.1 First Simulation (R1=300 and R2 = 300)

In the first simulation, the pipe is fully open with no restriction to water flow through the pipe. Since the diameter of the pipes is 300mm, we allow the diameter for both pipes in tank 1 and tank 2 to be set at 300mm, hence no restriction to the water flow.

The projection shows that if there is no restriction to the water flow– as the diameter of both pipes 1 and 2 remain at 300mm in 60 minutes– the water level in tank 1 will be 0.5832m, while the water level in tank 2 will be 0m.

5.2 Second Simulation (R1=300 and R2 = 200)

The projection shows that if there is no restriction to the water flow in pipe 1– as the diameter of both pipes 2 is reduced to 200mm in 60 minutes– the water level in tank 1 will be 0.5832m, while the water level in tank 2 will be 0m.

Hence, comparing the water levels in the tanks, it is seen that:

Tank 1:- the projected water level is 0.5832m, which is lower than the height of the tank, is 4.24m. In this situation, water will not overflow the capacity of the container.

Tank 2:- the projected water level is 0m, which is lower than the height of the tank, is 2.73m. In this situation, water will not overflow the capacity of the container.

5.3 Third Simulation (R1=300 and R2 = 100)

The projection shows that if there is no restriction to the water flow in pipe 1– as the diameter of pipe 2 is reduced to 100mm in 60 minutes– the water level in tank 1 will be 0.5832m, while the water level in tank 2 will be 0m.

Hence, comparing the water levels in the tanks, it is seen that:

Tank 1:- the projected water level is 0.5832m, which is lower than the height of the tank, is 4.24m. In this situation, water will not overflow the capacity of the container.

Tank 2:- the projected water level is 0m, which is lower than the height of the tank, is 2.73m. In this situation, water will not overflow the capacity of the container. Same as in the first case.

5.4 Fourth Simulation (R1=300 and R2 = 50)

The projection shows that if there is no restriction to the water flow in pipe 1– as the diameter of pipe 2 is reduced to 50mm in 60 minutes– the water level in tank 1 will be 0.5832m, while the water level in tank 2 will be near 0m.

Hence, comparing the water levels in the tanks, it is seen that:

Tank 1:- the projected water level is 0.5832m, which is lower than the height of the tank, is 4.24m. In this situation, water will not overflow the capacity of the container.

Tank 2:- the projected water level is 0m, which is lower than the height of the tank, is 2.73m. In this situation, water will not overflow the capacity of the container.

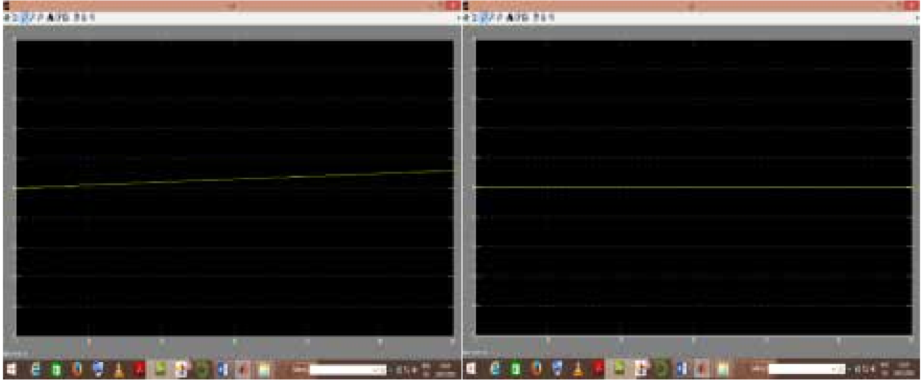

Fig. 4: Second Simulation (R1=300 and R2 = 200).

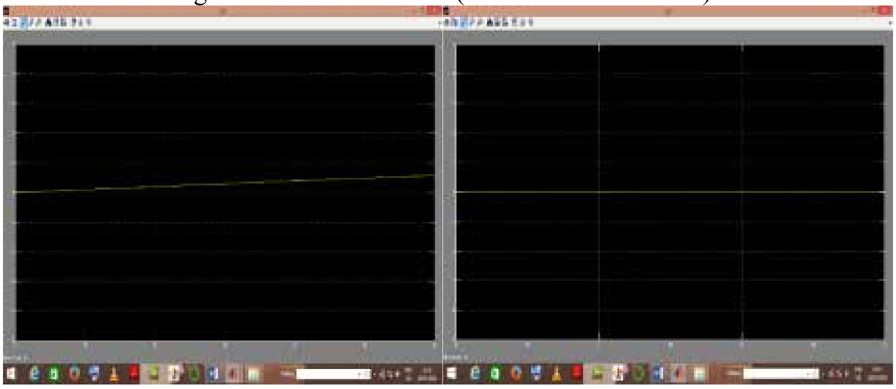

Fig. 5: Third Simulation (R1=300 and R2 = 100).

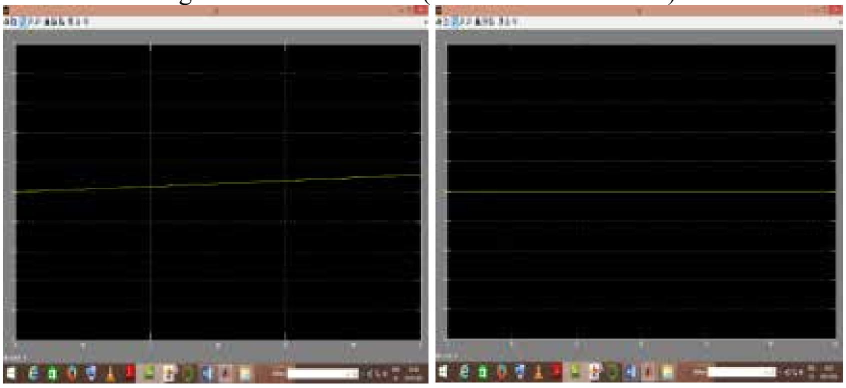

Fig. 6: Fourth Simulation (R1=300 and R2 = 50).

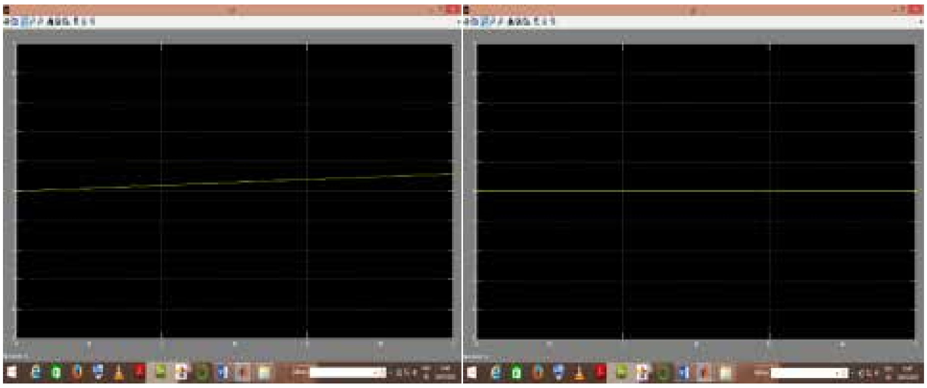

Fig. 7: Fifth Simulation (R1=300 and R2 = 25).

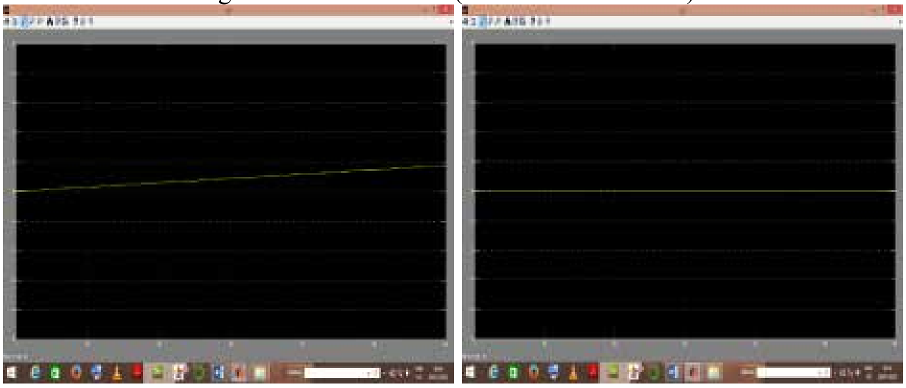

Fig. 8: Sixth Simulation (R1=200 and R2 = 300).

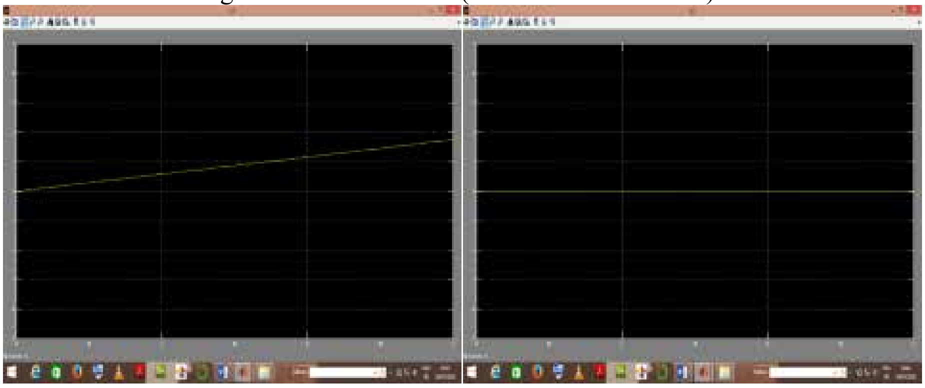

Fig. 9: Seventh Simulation (R1=100 and R2 = 300).

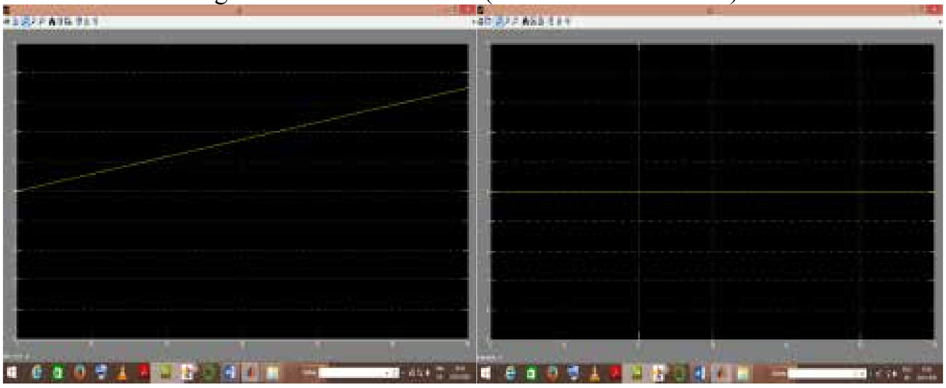

Fig. 10: Eighth Simulation (R1=50 and R2 = 300).

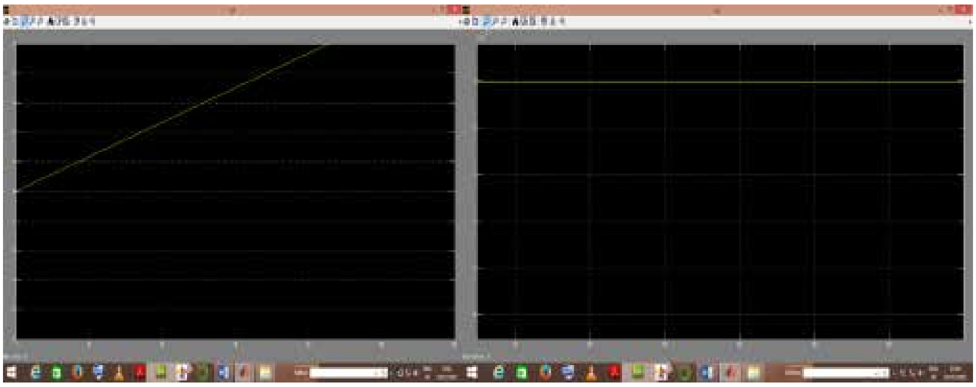

Fig. 11: Seventh Simulation (R1=25 and R2 = 300).

5.5 Fifth Simulation (R1=300 and R2 = 25)

The projection shows that if there is no restriction to the water flow in the pipe– as the diameter of pipe 2 is reduced to 25mm in 60 minutes– the water level in tank 1 will be 0.5832m, while the water level in tank 2 will be near 0m.

Hence, comparing the water levels in the tanks, it is seen that:

Tank 1:- the projected water level is 0.5832m, which is lower than the height of the tank, is 4.24m. In this situation, water will not overflow the capacity of the container.

Tank 2:- the projected water level is 0m, which is lower than the height of the tank, is 2.73m. In this situation, water will not overflow the capacity of the container.

5.6 Sixth Simulation (R1=200 and R2 = 300)

The projection shows that if there is no restriction to the water flow out of pipe 2– as the diameter of pipe 2 is reduced to 200mm in 60 minutes– the water level in tank 1 will be 0.8746m, while the water level in tank 2 will be near 0m.

Hence, comparing the water levels in the tanks, it is seen that:

Tank 1:- the projected water level is 0.8746m, which is lower than the height of the tank, is 4.24m. In this situation, water will not overflow the capacity of the container.

Tank 2:- the projected water level is 0.0m, which is lower than the height of the tank, which is 2.73m. In this situation, water will not overflow the capacity of the container.

5.7 Seventh Simulation (R1=100 and R2 = 300)

The projection shows that if there is no restriction to the water flow in pipe 2– the diameter of pipe 1 is reduced to 100mm in 60 minutes– the water level in tank 1 will be 1.7485m, while the water level in tank 2 will be near 0m.

Hence, comparing the water levels in the tanks, it is seen that:

Tank 1:- the projected water level is 1.7485m, which is lower than the height of the tank, is 4.24m. In this situation, water will not overflow the capacity of the container.

Tank 2:- the projected water level is 0.0m, which is lower than the height of the tank, is 2.73m. In this situation, water will not overflow the capacity of the container.

5.8 Eighth Simulation (R1=50 and R2 = 300)

The projection shows that if there is no restriction against the water flow in pipe 2 while flowing out– as the diameter of pipe 1 is reduced to 50mm, in 60 minutes– the water level in tank 1 will be 3.4942m, while the water level in tank 2 will be near 0.0005m.

Hence, comparing the water levels in the tanks, it is seen that:

Tank 1:- the projected water level is 3.4942m, which is lower than the height of the tank, is 4.24m. In this situation, water will not overflow the capacity of the container.

Tank 2:- the projected water level is 0.0005m, which is lower than the height of the tank, is 2.73m. In this situation, water will not overflow the capacity of the container.

5.9 Ninth Simulation (R1=25 and R2 = 300)

The projection shows that if there is no restriction to the water flow in pipe 2– as the diameter of pipe 1 is reduced to 25mm, between 40 minutes to 20 minutes– the water level in tank 1 will rise to 5m, while the water level in tank 2 will be near 0m.

Hence, comparing the water levels in the tanks, it is seen that:

Tank 1:- the projected water level rises above 5m, which is higher than the height of the tank, which is 4.24m. In this situation, the water will overwhelm the capacity of the container.

Tank 2:- the projected water level is 0.0m, which is lower than the height of the tank is, 2.73m. In this situation, water will not overflow the capacity of the container.

This work will aid proper projection of intended production behaviour and at the same time, provide the best operational parameters during production to avoid overstretching the capacity of the water plant during production.

6. Conclusion and Future Work

A water plant is made up of the following major components; they include the connecting pipes and the water tanks, which have been modelled, the results of the simulation have also been presented in this work. From the results, it is observed that: any changes in the connecting pipes restriction against water flow will significantly cause varying effects on the water levels in all the tanks. From the analyses, it was observed that varying any of the values of the connecting pipes affects the water levels in the various tanks.

The research is concerned with monitoring the water level into the flocculation chamber and the “clear well tank”. This is important because these two tanks represent the point of water entry into the plant (flocculation chamber) and the point of discharge of water from the plant (clear well tank). So, what comes from the flocculation chamber passes through a process and finally fills the “clear well tank”, this the need to monitor the source tank (the flocculation chamber) and destination tank (clear well tank).

Based on the above-stated reason, the mathematical model was developed and simulated in MatLab Simulink. The model depends on the resistance (R) of water flow between the connecting pipes and the capacity of the tanks (A). This is important because the rate of water flow through a pipe increases if the diameter of the pipe increases and decreases if the diameter of the pipe reduces. Therefore, in order to manage the water levels in the tanks, there is the need to be able to adjust and determine a comfortable pipe diameter for water to flow through the pipes as water flows into the relative tanks (tanks 1 and 2).

Based on this, we use the values R and A to observe the behaviour of the system. The restriction (R1) on pipe one (1) depends on the size of the pipe, its diameter, and this is same for the restriction (R2) on pipe two (2). However, from the model, the flocculation chamber is our tank 1 as earlier stated and is denoted as A1, while the clear well tank is our tank 2 represented as A2.

With the above-stated parameters, we simulated the production projection where our water inflow denoted as qi was given as 2100m3/h. On comparative bases, we varied the diameter of the pipes through which water flows in the plant, which is given initially as 300mm. This simulation adopts q1 = water level for tank 1, q2 = water level for tank 2.

This paper revealed that the volume of water in water plants storage compartments is directly linked to the amount of water entering the tanks and the amount of water leaving the tank. In an attempt to address the process control of the water plants storage compartments, we engaged in a case study research to develop and evaluate a model that analyzed the Greater Makurdi Waterworks water plant. Data were elicited from the plants operational manual. We developed a prototype tool to support the analysis. The tool is simple to understand. Also, the proposed approach produces solutions that allow the system operator to make decisions concerning the parameters for the plant during production.

The research has also provided answers to questions raised in previous researches. From [2], the paper focuses on the distribution of water to targeted destinations, and not focused on monitoring the storage compartments of water plants; this shortcoming is has been addressed in this research work. Also, according to [10], the research aimed at investigating only the amount of water consumed, but failed to account for the management of this water at the point of production. This shortcoming is also addressed in this research work.

This research has contributed to knowledge by providing a model that serves as a virtual tool for testing the system before embarking on real physical production, with this, the operator can quickly identify and correct errors before commencing production. In future works, research should focus on remote monitoring and detection of water levels in water plants storage compartments during production.

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