AUTOMATED SAND GRAVITY FILTER SYSTEM

By

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Submitted in partial fulfilment of the

BACHELOR OF SCIENCE IN APPLIED PHYSICS AND INSTRUMENTATION HONOURS DEGREE (HAPI)

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Midlands State University

GWERU

MAY, 2018

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ABSTRACT

Sand gravity filters can be automated to suit your requirements. Be it industrial or domestic this model can be implemented with ease. This research is mainly focused on getting sand gravity filters in industries automated using measurable variables like flow and level. The controls are based mainly on monitoring the filter tank level versus the outlet and inlet flows. Inlet flow and outlet flow are regulated to maintain a certain level beyond which the filter tank will be deemed flooding. With controlled flow certain levels in the filter tank signal clogging of the filters which will require cleaning using a backwash process. This process requires starting and stopping of pumps and air blower, hence using sensors and controllers the system can be automated.

DECLARATION

I, Busani Dube hereby declare that I am the sole author of this thesis. I authorise the Midlands State University to lend this thesis to other institutions or individuals for the purpose of scholarly research.

Signature:………………………. Date:………/…………/..……….

APPROVAL

This dissertation entitled "**Automated Sand Gravity Filter System**" by Busani Dube meets the regulations governing the award of the degree the **BSC in Applied Physics and Instrumentation Hounors** of the **Midlands State University**, and is approved for its contribution to knowledge and literal presentation.

SUPERVISOR………………………………..

ACKNOLEDGEMENT

Firstly my gratitude goes to the Almighty God, who is my pillar of strength in everything I do, for granting me the source of life and wisdom during this period of study. The following individuals also played a pivotal role in my research: My Classmates Andrew Banda, Victor Musapu, Mezha Nyoni and Prince Maukazuva, my Supervisors at work Engineer Ngonidzashe Dzumbira and Mr Arnold Piwa, Water Treatment Plant Operators at Hwange Power Station my course supervisors Mr G Manjengwa and Mr F Mazunga and not forgetting My family; Wife Doreen Dube and daughters Nomhle and Nothabo.

ABBREVIATIONS

ASF – Automated Sand Gravity Filter

AGF – Autonomous Sand Filter

HPS – Hwange Power Station

ZPC – Zimbabwe Power Company

WTP – Water Treatment Plant

PLC – Programmable Logic Controller

SCADA – Supervisory Control and Data Acquisition

IMS – Integrated Management System

SOV- Solenoid Valve

NC – Normally Closed Contact

NO – Normally Open Contact

DC – Direct Current

AC – Alternating Current

IC – Integrated Circuit

LCD – Liquid Crystal Display

cm – centimetres

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CHAPTER 1

1.1 INTRODUCTION

In today's world, there is a continuous need for automated appliances and devices. With the improvement in standard of living, there is a sense of urgency for developing circuits and computer programs that would ease the complexity of life like doing things manually. With the advancement of technology that has led to a lot of great discoveries, our day to day living has changed to such an extent that we no longer have patience in doing anything manually [1]. For instance when someone misplaces their cell phone, the first thing to do is to ask someone to call it than looking for it manually [2]. That is how people are now programmed to do things in a simple way.

Often people tend to go through hectic times trying to get their drinking or process water to be purified. Some have to do it manually which takes a lot of time which is boring. Also this can lead to wastage in water spillages as human error cannot be completely eliminated and this can cause problems to the end users, for instance if it is water for drinking contaminated water can be produced leading to dangers to human life. For power plants, errors in processing water for the plant process can be very costly [3].

1.2 BACKGROUND

Hwange Power Station is a Thermal Power Station located about 47km away from Zambezi River which is the main source of water. From Zambezi the pump station is made up of 6 x Low lift pumps which collect water directly from the river and pump it to settling tanks located about a kilometre away from the river. From the settling tanks there are also 6 x High lift pumps which are responsible for pumping water into the Power Station Reservoirs which are at a higher point from the station [4]. Raw water is used for steam cooling and on the other hand boiler/steam water need to be purified. Water from the reservoirs flows to the cooling plant and water treatment plant due to gravity because the reservoirs are strategically located at a higher point from the power station, through opening of some valves according to the raw water demand in power station.

There is a huge demand of purified water which undergoes through a purification process which starts with removal of solid objects like algae and animal waste in a clarifier [5]. Then it goes through sand filters which remove all form of mud and other suspended matter which the clarifier unit could not remove to give clear water that is stored in a filtered water tanks before it is further purified for specific purposes that range from Boiler/steam water to drinking water [6]. Up to this level the filtration process is done manually and thus more often the plant operators complain about the manual operation and that is our problem. Otherwise the rest of the operations after the filtration process have been automated.

1.3 MOTIVATION

By closely looking at the plant setup, the researcher discovered that the plant can be easily automated while maintaining the same setup of the plant by simply adding some control devices like level sensors and control valves controlled through a control system like SCADA (Supervisory Control and Data Acquisition) and PLC (Programmable Logic Controllers) [7].

This therefore led to the thought of having a project to address this crisis of manual control of the Sand Gravity Filters at Hwange Power Station hence the **AUTOMATED SAND GRAVITY FILTRATION SYSTEM.** Such a system at the Power Station will complete the automation of the Water treatment plant processes and will make the life of the Plant Operators simple. There will be no need for them to keep the whole day checking the levels of the tanks, opening and closing valves and starting and stopping pumps manually. Such a system can be implemented in any water purification process ranging from domestic plants to large industrial plants.

1.4 Aims of the study

- To design controls of an **Automated Sand Gravity Filtration System** that will suit the already existing water treatment plant structures at Hwange Power Station

1.5 Objectives

- To integrate control variables such as flow, level, temperature and pressure to automate the water treatment plant filtration process.
- To make amendments and changes without completely shutting down the plant

- To limit water spillages due to over flow.
- To improve the efficiency of the plant.
- To make the plant user friendly for the Plant Operators.

1.6 HYPOTHESIS

Filtration is a method of separating solids from liquids such as water in which the liquid passes through a porous medium to remove colloidal or suspended impurities [8]. At a young age the researcher had an experience with sand filters during the cattle herding days by the river banks, when people got thirsty, they would dig in sand and within a short time clear water would fill the hole and the assumption was that the water was clean and safe for drinking. Up to date people living in primitive rural areas still use the same principle to get drinking water from rivers in Africa. This process is called Bank Filtration [9]. Sand gravity filters are the most common type of filters used to filter water. They are made up of layers of granular material (sand and gravel) of different sizes, with gravel which is coarser at the bottom of the filter and Sand with finer granules at the top. This set up allows water to sink through the filter due to gravity eliminating the impurities when the water is fed from the top of the filter [10]. Filtration undergoes through four basic mechanisms and these are segmentation, interception, diffusion and inertia [11] [12].

Automation is the use of machines to do tasks or jobs that were once performed by human beings. In general it implies the integration of machines into a self-governing system using controllers [13]. Controller is a device, which in the past used mechanical, hydraulic, pneumatic or electronic techniques often in combination, but in modern days is in the form of a microprocessor or computer, which monitors and physically alters the operating conditions of a given dynamical system [14].

1.7 SIGNIFICANCE

By applying the principles of Automation, Controllers, and Gravity filtration (which are in the scope of Applied Physics and Instrumentation) this project address the problem of manual water purification processes in areas like Hwange Powers station (Which has a high demand of purified water) and other organisations or domestic areas which require self-purified water.

Basically it is not proper for big organisations like Zimbabwe Power Company (ZPC) to be still lagging behind in control technology. Hence this project can be a starting point for continuous improvement. As the Power Station is embarking on an Integrated Management System (IMS), automation of the plant is part of the programme [15].

1.8 CONCLUSION

Moving with technology, automated sand gravity filters is what many water purification plants lack in Zimbabwe. By successfully implementing this system in Hwange Power Station some other organisations like town councils can buy the idea and even individuals can who want to do for domestic use can do it on a smaller scale as this model is not limited to Hwange Power Station only.

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CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter serves to review the current set up at the plant understudy at Hwange Power Station and the suggested changes directly suitable for this plant that are in line with automation and filtration principles. There are many set ups of filters and each type has its advantages and disadvantages. For this study the researcher had to analyse and get the best method to suit the already available structures at Hwange Power Station without incurring construction expenses and probably stopping the operations during modifications. Below is the top view of the plant which shows the clarifier and the Sand gravity filters.

2.1 TERMINOLOGY

Clarifier – A unit where the raw water is first collected and mixed with chemicals to eliminate suspended matter before the water gets into the filters [1].

Clarifier inlet valve - the valve which opens to let raw water into the clarifier [1].

Filter gate/inlet valves – Some spade valves which are used to isolate the filter from the inflow of clarified water [1].

Filter – the tank which is designed with the filtration medium where clarified water is collected and let to sink through the medium and flow into the next tank due to gravity, leaving unwanted dirty in the form of mud and other suspended matter [1].

Filtration medium – The sand of different texture which is used for filtration, usually packed strategically such that the coarser is at the bottom and the finer one at the top [1].

Filter outlet valve – the control valve that allows water to flow out of the filter into the filtered water tanks [1].

Filtered water tanks – The tanks that serve as storage for the filtered water [1]

Backwash tank – The tank that is connected in cascade with filtered water tanks to supply water during backwashing process [1].

Backwash pumps – Electric water pumps used to pump water back into the filters during backwashing [1].

Backwash inlet valves – the valves to each filter that allow water from the backwash pumps to flow through [1].

Air blower Compressor – The source of compressed air used to backwash.

Blower valve – the valve that opens compressed air for backwashing into the filter.

Sand filters - constructed beds of sand or any other suitable granular material that can allow water to flow through while eliminating suspended matter [2].

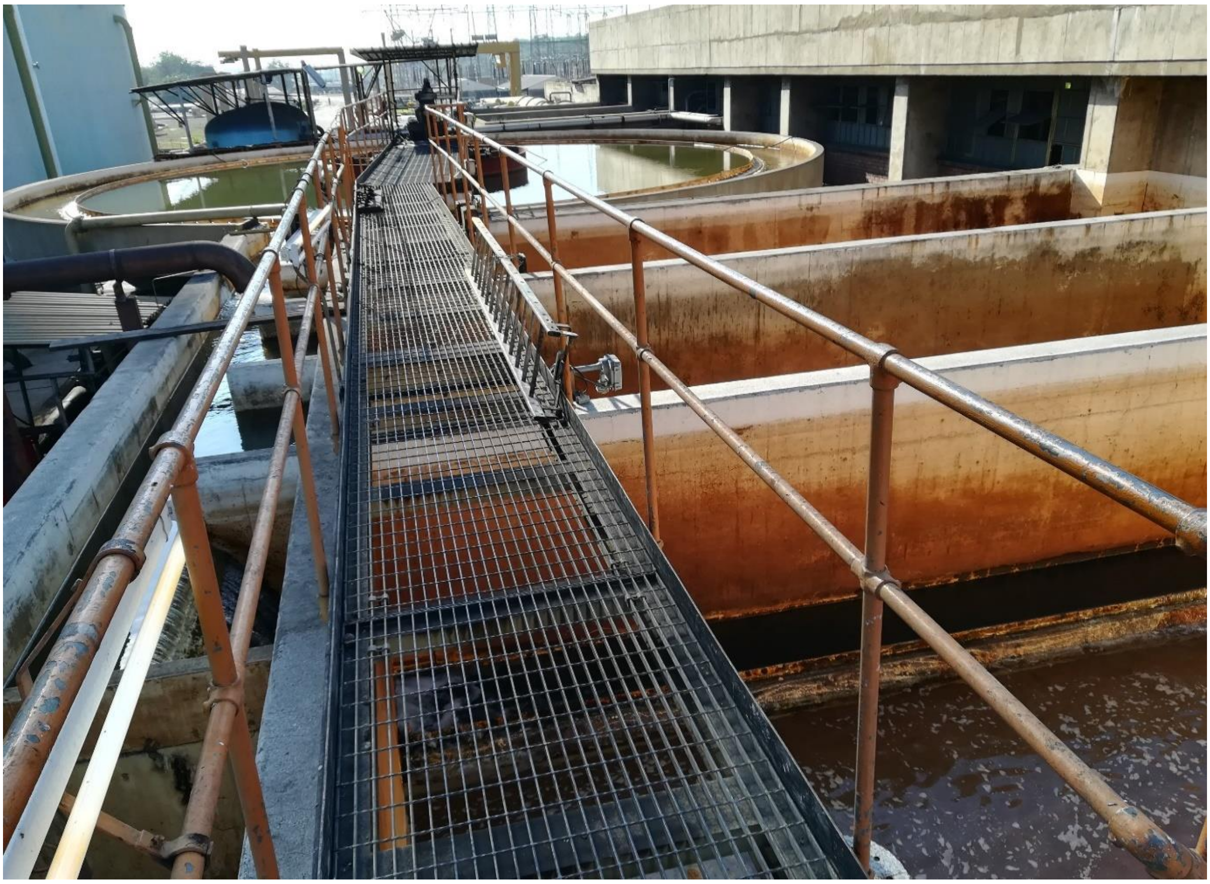


FIGURE 2.1 – Top view of the HPS WTP Filters

2.3 INITIAL FINDINGS

The current set up has the raw water continuously fed into a clarifier unit at a flow rate which is pre-set and believed to be the best as determined by the experience of the operators. The chemical dosing in the clarifier is also done manually but it was observed that with online analysers it can also be automated with ease, but this study is just focussed on the automation of the gravity filters. The disadvantage of this pre-set flow rate into the clarifier is that it is not controlled. The images below show the clarifier top view and the bottom view which has the clarifier inlet valve [3].

Figure 2.2 Top view of the clarifier unit

Figure 2.3 Bottom of the clarifier and the clarifier inlet valve

The water from the clarifier flows into the Gravity filters through some pneumatic operated spade/gate valves (filter inlet valves) which are basically for determining which filter is in service as they are either closed or open fully. [3] As the water sinks into the Sand in the Gravity filters it has its rate of filtration determined by the Area of the filters, under drainage system, that is, total area of drainage holes, depth of filter, and number of filters. [4] This sees the Plant Operators in the current set up having to open and close the filter outlet valve manually when the level of the filtered water tank if full. The outlet flow rate of the filter is not controlled [3].

Figure 2.4 – The filter

As the water is filtered through the sand, mud and other particles that could have passed through the clarifier tend to clog the filters, thereby causing the water level in the clarifier to rise regardless of the position of the filter outlet valve. In such instances the Plant operator stops the filtration process and initiates the backwash process which involves starting of the backwash pumps that takes filtered water from the backwash tank that is cascaded with Filtered water tank. Simultaneously they start the air blowers with the backwash pumps and thus the back wash process. During this process the clogging material is flashed back (floating) and as the level in the filter tank rises due to the backwash inlet, a drain valve is opened to allow the dirty water to flow away to the dirty drains. The backwash process is allowed to takes place until the water is visibly clean. After that the Plant Operator initiates the filtration process again by stopping the air blower and the backwash pumps [3].

It can be clearly seen that without automating the plant this process of filtration and backwashing can be tiresome and boring to the Plant Operators as they need to keep a constant eye on the levels to avoid over spillages and water losses to the dirty drains in the event that the Filter tanks flood with no one monitoring [3].

However this study reveals that with the current set up without any major structural changes to the plant, these processes, that is, the filtration and backwashing processes, can be automated with ease.

2.4. FILTER DESIGN

In order to attain and maintain levels and flow, uniform in the automated system the filter has to be designed in such a way that the filtration rate sustains the water demand in the plant or by end users. The parameters to be considered are as follows:

- Design a rapid sand filter to treat – Size of the filter itself
- Amount of backwashing water required
- Backwashing time per day
- Rate of Filtration
- Number of Filters required
- Length/ Width of Filters
- Depth of filtration Medium

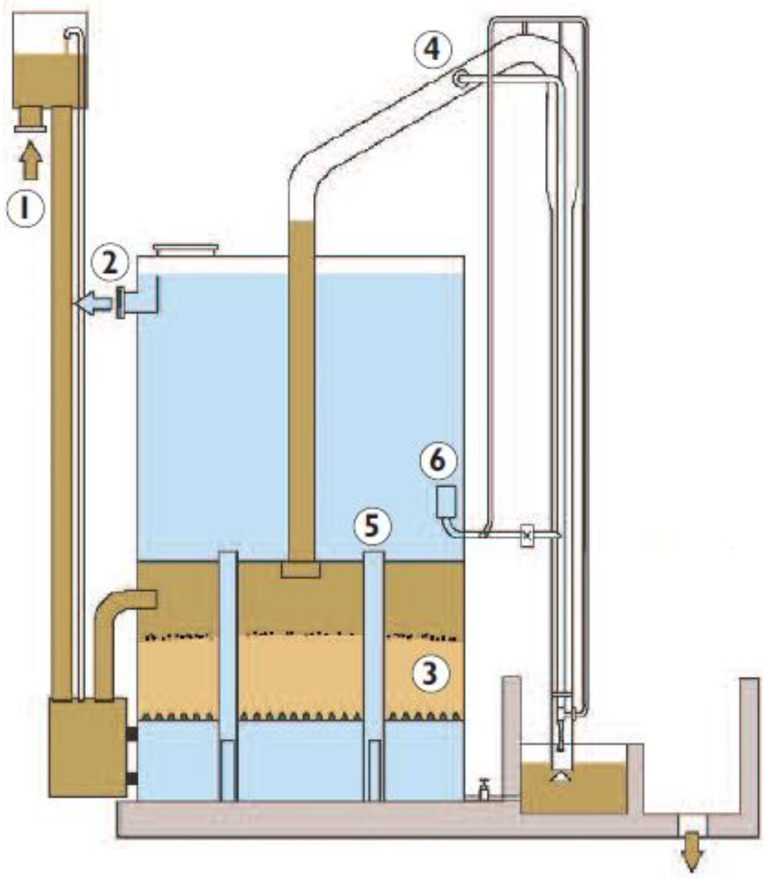
Through mathematical calculations the designers can deduce the right size of the filters to obtain the area of the filter and the underdrainage system, that is, Total area of holes required and the area of the manifold [4].

2.5 OTHER DESIGNS Example

2.5.1. The Autonomous Sand gravity Filter

This system is said to be virtually a no running costs model. It is completely automatic and totally self-contained and operates with no instrumentation, backwash pumps or similar. The system is designed to backwash when need arises and it is initiated automatically without human involvement [5].

These filters can work for long periods without any operator attendance or maintenance whatsoever. Filtration in the AGF filter is also excellent since conservative ratings are used together with a uniform backwash rate and volume ensuring that the sand bed being backwashed is always maintained in optimum condition [5].



[5]

Figure 2.5 -The Autonomous Gravity Sand Filter (AGF)

1. Raw water is let to the filter through a header tank after which it is fed into the central filtration area where contaminants are retained.

2. The filtered water then sinks into the bottom filtrate collection area from where a number of pipes transfers it to the top backwash storage tank.

3. As contaminants (suspended matter) accumulate in the sand-bed a pressure drop develops which causes a rise in the level of the column of water in the backwash pipe.

4. At a built-in maximum water level, a flow of water occurs through a simple evacuation system that initiates the backwash within a short period.

5. The fixed volume of filtered backwash water which is stored within the unit is passed back under the sand bed which expands and contaminants are removed via the backwash pipe to drain.

6. The backwash is terminated when the backwash storage compartment is depleted. On completion of backwashing the filter reverts to filtering mode, re-fills itself and flow to service is once again established [5].

However this design is not compatible with the area of research as the structures are already built.

2.6 THE CONCEPTS BEHIND HWANGE DESIGN

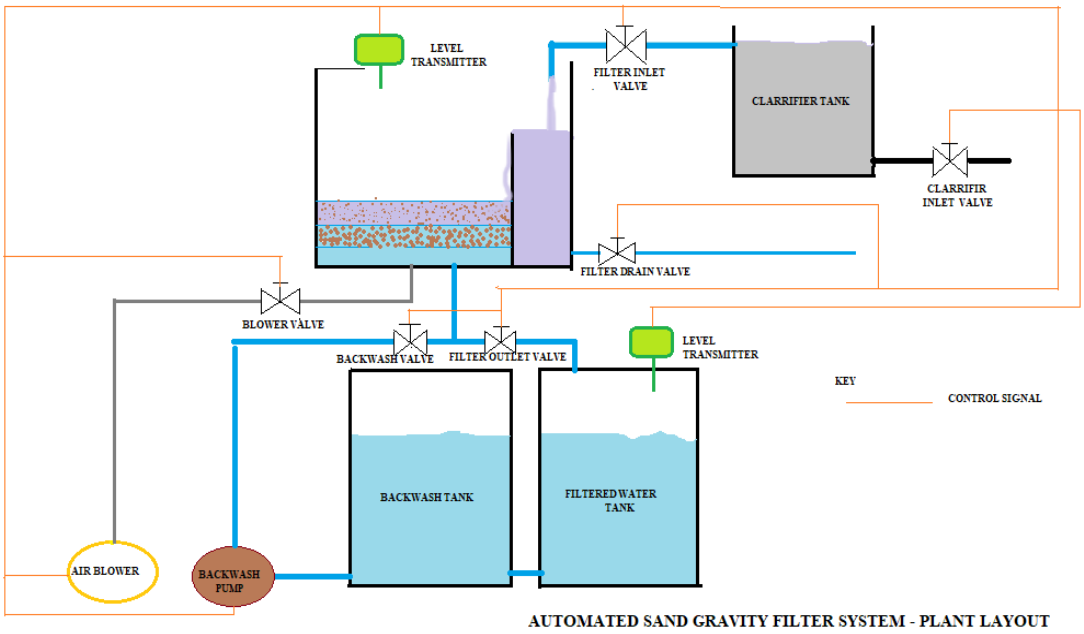


Figure 2.6 – Plant under study layout

Starting from the clarifier inflow, for the clarifier inlet, a control valve which will be controlled by the level of the filter water tank is needed. The valve is fully open when the filtered water tank is empty and will be fully shut when the filtered water tank is full. Thus the position of the clarifier inlet valve is set to be inversely proportional to the level of the filtered water tank. Also the clarifier inlet valve will automatically close fully when backwash process is in progress.

For the filter inlet, the operator will select the duty filter thereby opening the gate/spade valves which will open and feed water into the filters at the same rate as the clarifier inlet since the output from the clarifier is just an overflow due to inflow from the inlet valve and hence this overflow is the inflow to the filters. The flow rate into filtered water tank from the filters is determined by the filter depth, filtration area, the underdrainage system, and the filtration medium. As a way to control the level of the water in the filter the filter outlet valve position is programmed to be directly proportional to the level of the same filter. In other words the filter outlet valve regulates the gravity filter flow.

When the filter level rises to a very high level it will be a sign of clogging of the filter due to mud and other filtered matter. The controller will initiate the backwash process immediately there by shutting the filter outlet valve, starting the backwash pumps and the air blower compressors. As the filtered water pumps and air blower compressors are started the backwash inlet valves and air inlet valves open respectively.

Since the backwash pumps will be pumping water back into the filters, the level will rise until water overflows into a drain valve which will open and flash the dirty water into the dirty drains. The backwash process is timed to run long enough for the water in the filter to eventually become clean and clean. After the backwashing process has elapsed the backwash pumps and air blower compressors stop immediately and there by shutting the backwash inlet and air valves instantly.

At this instant since the level of the filter would be very high, the filter outlet valve opens fully and thus, this will cause a rapid filtration lowering the level of the filter since the filter would also be clean too. On the other hand, as the backwash process stops, the filtration is initiated starting from the clarifier inlet valve which is controlled by the filtered water tanks level.

The cycle will go on and on until the tanks are full, that is if there is less demand from the filtered water tanks to the end users or further processing of the water. When the filtered water tanks are full, the clarifier inlet valve will be fully shut there by stopping the overflow from the clarifier which is also the inflow into the filters.

2.7 CONTROL AND AUTOMATION

Different types of level measurement techniques can be used but for this purpose the technique to be use should possess the ability to have a control output to our control valves and also initiate starting and stopping of the backwash pumps and air blowers.

2.7.1Conductivity sensor level controllers

The initial set up was using conductivity probes with londex controllers which will just give discrete outputs at different levels, that is, for low, very low, high and very high levels. This has the ability to just start and stop devices but will never give a signal to control valves. Also it has the disadvantage that the probes are directly in contact with the process, thus they need constant cleaning as dirty accumulation on them will affect sensitivity. With high current switching the controller contacts are also bound to be damaged hence an extra high voltage circuit has to be incorporated alongside a control circuit.

Below are some typical set ups of conductivity level controllers.

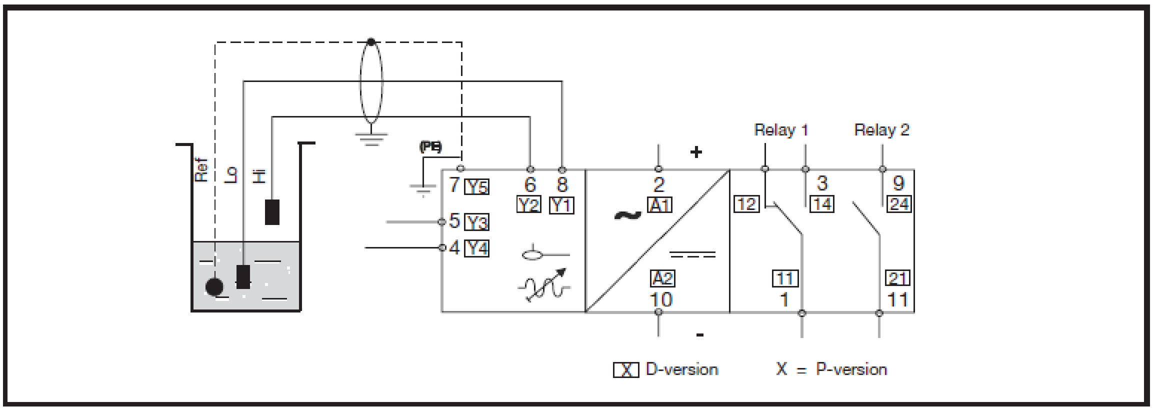


Figure 2.7 – 3 sensing probe – Level controller [6]

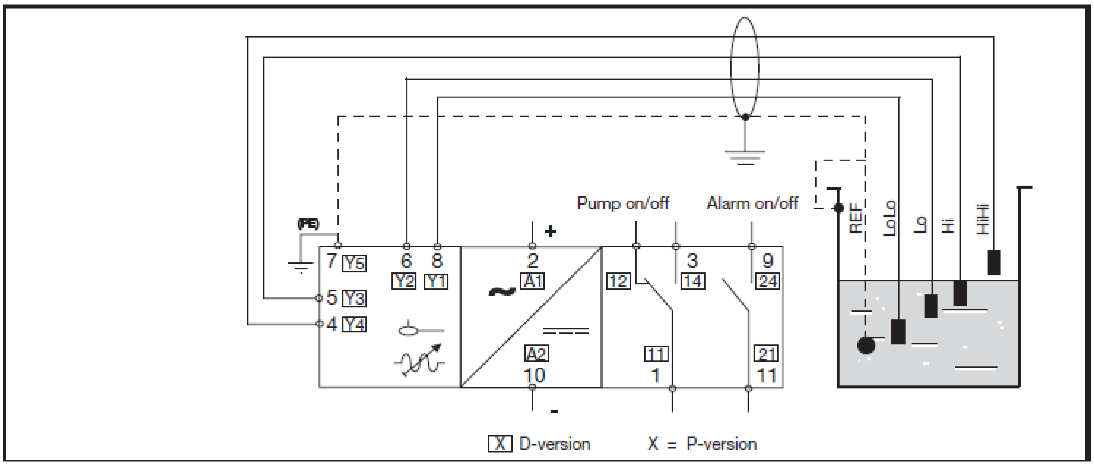


Figure 2.8 – 5 sensing probe – Level controller [6]

2.7.2 Pneumatic level Controllers.

This type of controller that can be used with pneumatic control valves and these type of controllers can be used for the clarifier inlet and filter outlet valves. However the major setback is that the control air can easily accumulate moisture, and hence can cause failure of the controllers. As a result effective air driers need to be installed alongside the control air compressors. Ideally the output (control air) of the level controller will vary according to level. Depending on the type of the control valve, whether it is air to open or air to close, the set up will be directly or indirectly proportional to the level. For air to open valves, as the level go down the control air output from the level controller also increases causing the spring loaded control valve to open further and thus for air to close control valves the controller output will be set to increase with level.

The controller/transmitter receives the change in fluid level, fluid-to-fluid interface level, or density from the change in the buoyant force the fluid exerts on the sensor displacer. The displacer, through a mechanical linkage, imparts a rotary motion to the torque tube shaft. This rotary motion positions the flapper according to the level position of the displacer; the nozzle/Bourdon tube arrangement sends a pneumatic signal to the control valve.

Figure 2.9 – A Typical Pneumatic float level controller

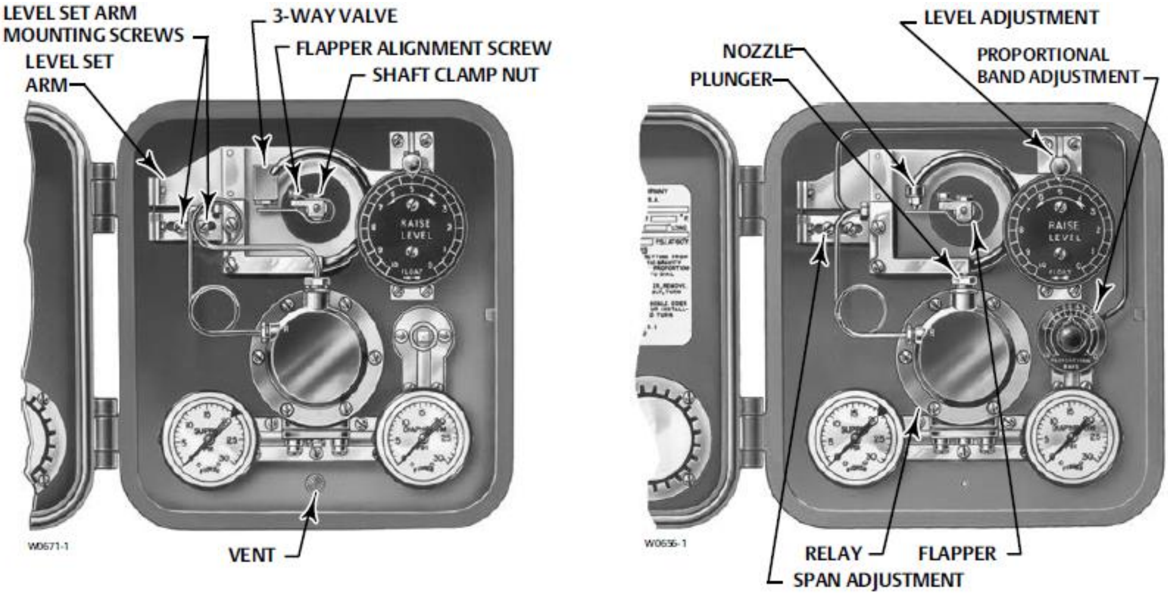


Figure 2.10 - interior or a Pneumatic level controller [7]

With clean air with sufficient driers this type of control can be applicable to our plant even though it also needs more air impulses lines depending on the distance between the controlled level and the control valve.

This type of controller is mostly used to control valves but for our application whereby we need to start and stop machines relating to the controlled level, from a careful analysis, a pressure switch can be incorporated but however some other control parameters needed for our system like time of operation cannot be incorporated. Or else more components like timers have to be added in control circuits.

2.7.3 Prosonic level controller.

This one kind of controller with the capabilities of many types of controllers all in one and have the advantage that it is not in contact with the process. It possess an analogue signal that is in the form of 4-20mA and can be decoded by the controller according to the set parameters to give the actual level and further control our control valve. In this scenario the control valve will be an electric one instead of the pneumatic. For our plant the controller is a PLC (Programmable Logic Controller) and SCADA (Supervisory Control And Data Acquisition) system which is already in use for other systems and processes [8].

The prosonic level controller is also embedded with on off control capable of controlling up to five different on off devices controlled at different levels depending on the controller type.

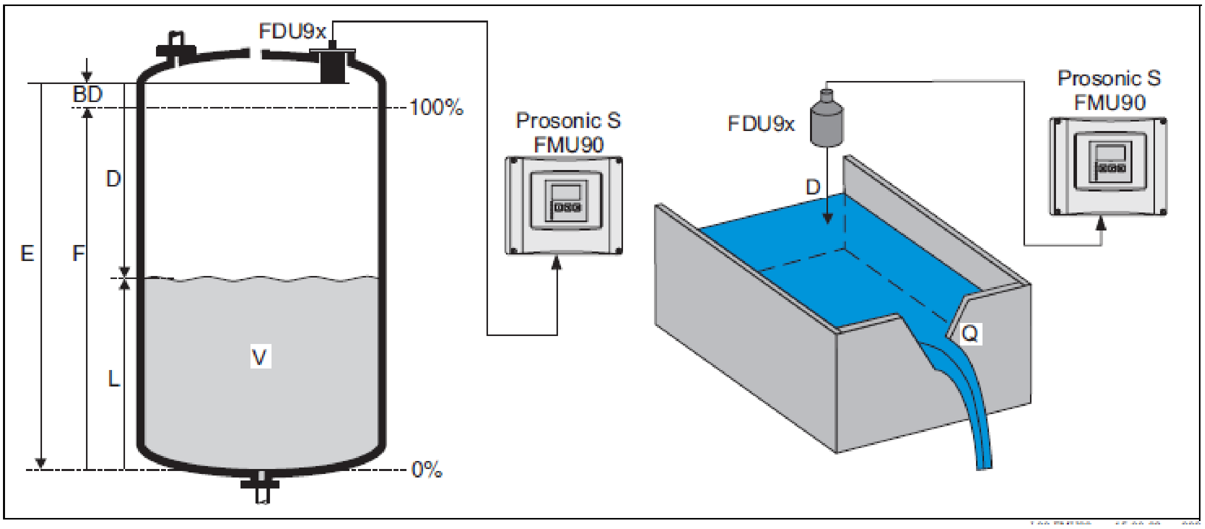


Figure 2.11 – Prosonic level control block diagram

BD: blocking distance; **D:** distance from sensor membrane to fluid surface; **E:** empty distance **F:** span (full distance); **L:** level; **V:** volume (or mass); **Q:** flow

The sensor transmits ultrasonic pulses in the direction of the product surface. There, they are reflected back and received by the sensor. The transmitter Prosonic S measures the time (t) between pulse transmission and reception. From t (and the velocity of sound [c]) it calculates the distance (D) from the sensor membrane to the product surface:

$$D = c \times \frac{t}{2}$$

Equation 1

Where: D is the distance between sensor and surface of the surface of the substance measured, c is the speed of signal, t is the time taken by the signal to return to the sensor.

2.7.4 Control Valve

The control valve is one of the most critical part of the control loop. It manipulates a flowing fluid, to compensate for the load disturbance and keeps the regulated process variable (In our case) as close as possible to the desired set point. The analogue output from the prosonic level controller, becomes the control input signal to the electrically controlled control valve.

In case of a pneumatic level controller the valve usually is spring loaded and the controller output and the spring stiffness are calibrated accordingly. Hence if the valve is put on auto, it will start controlling the flow automatically according to the controlled level as a result of the controller output, that is current for the electric valves and control air in pneumatic valves) [9].

2.8.5 Control System

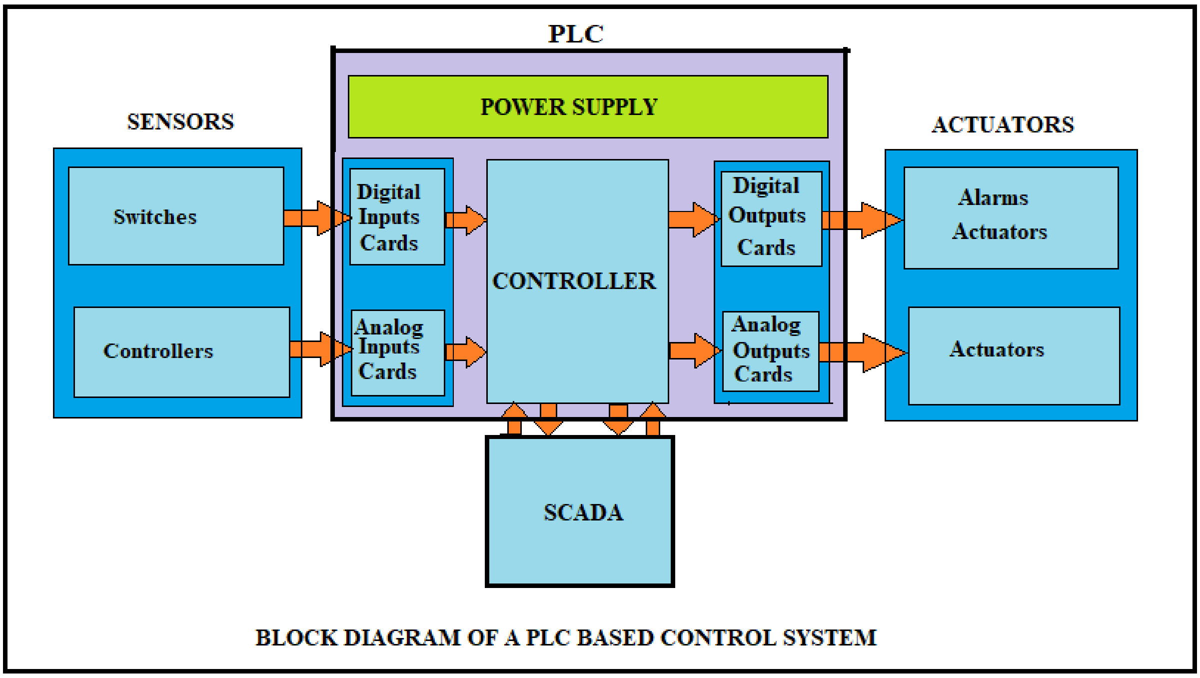


Figure 2.12 – PLC Based control system

Above is a typical PLC Block diagram that suits the controls of our plant process. Within the controller lies the Central Processing Unit (CPU), Memory and Programming session. Hence a PLC consists of five major Components, which are: Power Supply, Memory, Central Processing Unit (CPU), Logic Solver, I/O Interface and Programming Section [10].

2.5.5.1 Power Supply- PLCs are generally powered from AC mains and power supply system converts ac voltages to required dc voltages [10].

2.5.5.2 Memory - Program memory receives and holds program instructions. Data memory is used to temporarily hold data generated from processes or acquired through I/O devices. [10]

2.5.5.3 Processor - a micro-processor based CPU and is the part of PLC that is capable of reading and executing program instructions and data [10].

2.5.5.4 Program loader - is used to enter/change the user program into the memory and to monitor the program execution [10].

2.5.5.5 Input/ Output (I/O) Modules - acts as the eyes, ears and hands of PLCs.

- **Digital Inputs and outputs** - signal is discrete, such as ON/OFF, OPEN/CLOSE, energized/de-energized. Examples of discrete inputs include push-buttons, selector switches, joy sticks, relay contacts, pressure switches, level switches, starter contacts, temperature switches, flow switches, limit switches, photo-electric switches, and proximity switches, while digital outputs include light, relays, solenoids, starters, alarms, valves, heating elements, and motors [10].

- **Analogue inputs and outputs** – used in complex systems that needs data. Examples of analogue inputs include potentiometers, temperature transducers, level transducers, pressure transducers, humidity transducers, encoders, bar code readers, wind speed transducers, while analogue outputs include analogue meters, digital meters, stepper motors (signals), variable voltage outputs, and variable current outputs [10].

This becomes the engine of the process/plant control. It eliminates a lot of hard wired component, like relays and other small complementary devices. Basically a program is written according to plant specifications defining the inputs and outputs of the controller and all operating parameters. Each controller has its programing language.

As mentioned earlier on, that part of the Water treatment plant is already automated, there is a Programmable Logic Controller (PLC) already in use in the plant and it has extra/spare input/output modules that can be utilised for our controls. All what is needed is to modify the already existing program and add the program for the gravity filters.

Nevertheless for continuous operations of the plant a standalone PLC can be purchased if funds permit such that the already existing plant controls cannot be compromised. PLCs can be linked with wireless SMART sensors [11].

2.9 WHY AUTOMATE?

Filtration takes place in three phases which are: a) backwashing period where the filter efficiency is increased; b) a period of maximum efficiency, that is soon after filtration; and c) a period of clogging and deterioration in filter efficiency determined by the available pressure head [11]. The first phase happens after initiation or starting of pumps and blowers which also need to be stopped. Also the whole process involves opening and closing of valves. As a result there is great need to automate.

2.10 CONCLUSION

From previous researches it is very possible to change Hwange Power Station Sand Gravity Filters to become an Automated Sand Gravity Filter System.

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CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter explores the methods used to come up with the actual set up of the plant, that is, the choice of set points and equipment used in the existing plant design. The components and materials used can be seen that they imitate the real plant. The challenge with the exact plant equipment was the size of the items and compatibility with the place of presentation environment.

3.2 COMPONENTS AND SET UP

As our project is mainly focused on the automation of the filtration plant the researcher tried as much as possible to use the available resources to make a prototype which will illustrate clearly what the actual project will be like. From the previous chapter the setup is as shown in figure 2.5 where it is seen that it is starting from the clarifier inlet valve up to the backwash system. For clarity we will bring down the drawing.

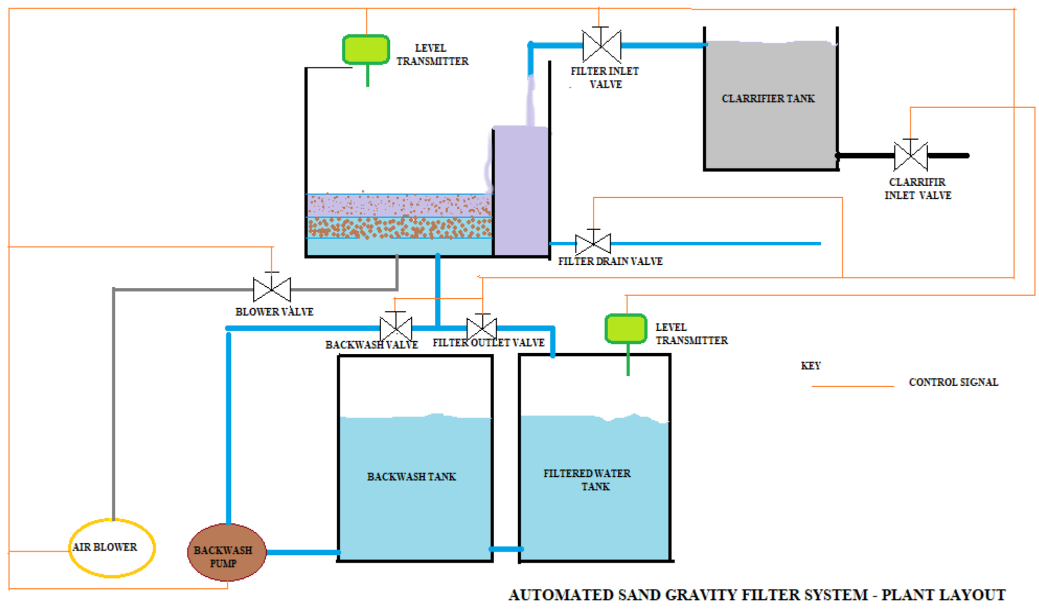


Figure 3.1 – Plant layout

For all the valves 12vdc solenoid valves were used, hence there will be no analogue controls of the valves, meaning they just open and close. For the tanks simple buckets were used, for backwash pump is a small 12Vdc water pump with the capacity of 5L/min and for the air blower we used a simple 12Vdc compressor.

The pipe work system uses ¼” plastic impulse lines connected through ¼” fittings matching with the solenoid valves. As for the level control and measurement ultrasonic sensors compatible with Arduino controllers were used. In place of the PLC an Arduino controller was used. For display purposes a 16x2 LCD was used.

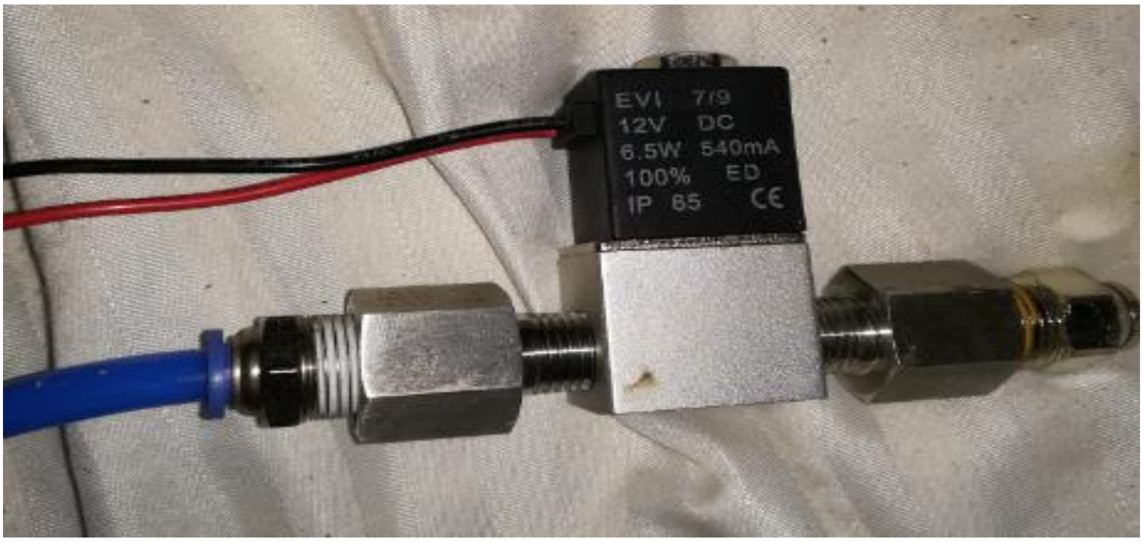


Figure 3.2 - 12Vdc Solenoid Valve with connections

Figure 3.3 – 12Vdc Solenoid valve with connections

5.2.1 Solenoid Valve (SOV)

A solenoid valve is an electromagnetic valve used to control gases or fluid flow. By supply an electric field the valve position changes to either closed or open depending on its normal state. In this case normally closed 12Vdc SOVs are used. This means that when a signal of 12VDC is supplied to the coil of the SOV the valve will open and shuts off when the voltage is switched off. There so many types of Solenoid valves classified in terms of the voltage used (whether DC or AC), number of ways in which they operate (1-2 way, 3-2 way, 5-2 way), action (single or double acting), normality (normally closed or normally open) and controlled variable (fluids or gases or both). Figure 3.2 shows a 12Vdc, 1-2 way, normally closed, water and air solenoid valve while Figure 3.3 shows a 12Vdc, 1-2 way, normally closed, water valve [1]. They also differ according to manufacturers.

The valve in figure 3.2 can be used for either water or air control that is why it was used for the air inlet, backwash inlet and filter outlet valves. While the valve on Figure 3.3 is strictly for water controls hence it was used as the drain valve.

Figure 3.4 – 12V dc Pump Mounted

3.2.2 Electric Water Pump

Water pumps also come in different sizes and ratings. Figure 3.4 is a 12V dc 280L/hour Brushless Motor Submersible Water Pump used in this project. It is a low power consumption device but with high efficiency. Can lift up to 5m. Its size is very suitable for small project like this one [2].

Figure 3.5 – Air Compressor

3.2.3 Air Compressor

Figure 3.5 above is an image of a compressor which was eventually used in this project after the ordered smaller compressor is still bending delivery. The compressor serves the purpose of a blower but however it complicated our circuit as it draws higher current than any other devise in this project. As a result a higher current relay was sourced.

3.3 WORKING PRINCIPLE

Working with the above set up the automated principle is as follows:

- The clarifier inlet valve opens for as long as the level on the filtered water tank is not high which is 25cm from the filtered water tank level sensor according to the prototype and also the backwash process should not have been initiated. Once the high level or backwash has been activated, the clarifier inlet valve closes instantly to stop the filtration process.

- The filter inlet valve stays open for as long as the Clarifier inlet valve is open during the filtration process.
- The filter outlet valve also opens for as long as the clarifier inlet valve is open.
- Once the filter tank level sensor reaches a very high level set point, the filtration process stops instantly and the backwash process begins.

NB: the cause of the water level to rise in the filter tank is the clogging of the sand filters by accumulation of mud. So the backwash process is to flush out the mud using the clean water from the backwash water tank which is cascaded with the filtered water tank.

- During the backwash process the all the filtration related valves, that is, the clarifier inlet, filter inlet and filter outlet valves, are closed.
- Backwash process initiates the starting of the air blower compressor and the backwash pump.
- The backwash inlet valve opens simultaneously with the starting of the backwash pump while the air valve opens with the starting of the air blower compressor.
- The filter drain valve opens during backwash so that the mud and the dirty water is disposed to the dirty drains.
- The backwash process is timed to run about 2mins after which the filtration process start again.

The above filtration and backwash process take place automatically without much of human involvement, solely depending on the ultrasonic sensors which send signals to the microcontroller which is the engine of the controls of the system.

Next is the Control circuit, power circuit, and Arduino program for the above set up.

NB: there is no definition for a compressor or blower in the Arduino programing language hence the compressor was programed to be in parallel with the pump.

3.3.1 Control circuit schematic diagram

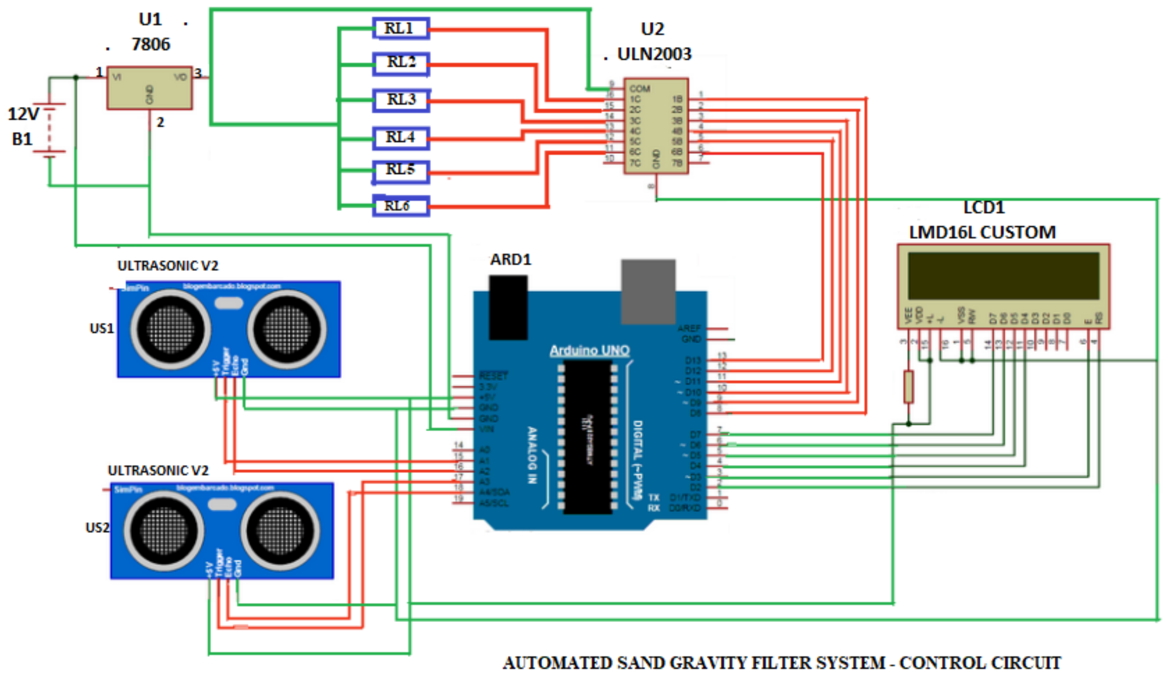


Figure 3.6 – Control circuit schematic for the full system [3]

3.3.2 Power Circuit Control diagram

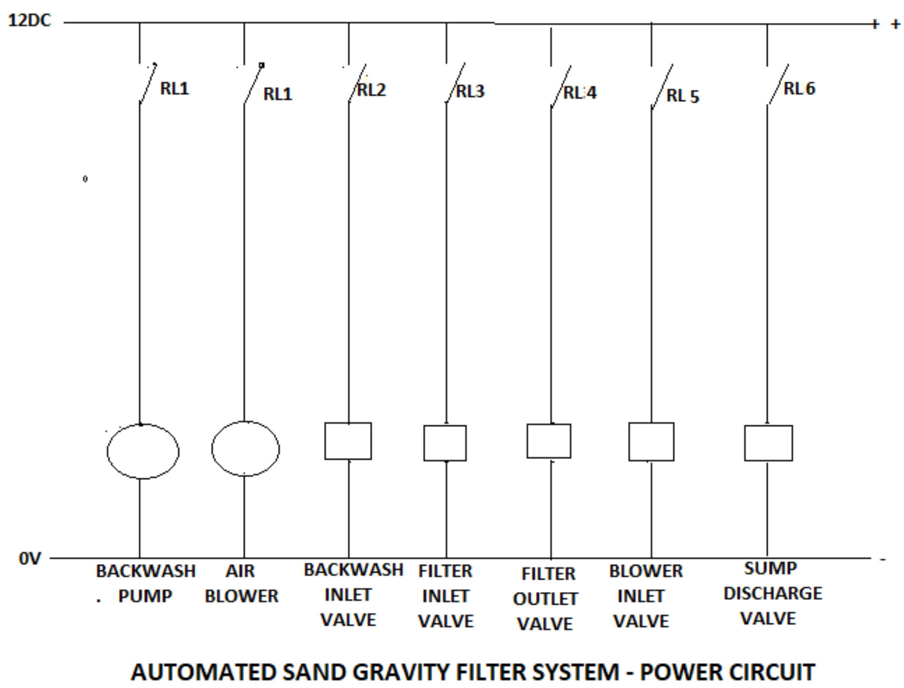


Fig 3.7 – Power circuit for the full system

3.4 ACTUAL SET UP

Due to the fact that presentation venue does not permit the researcher to do a lot of dynamic things for the prototype, like there is no source of running raw water, in as much as we would have loved the whole set up, we will now dwell much on the filtration part of the project which is the objective of this project and do away with the clarifier part. Also the two cascaded tanks in the form for the filtered water tank and the backwash water tank will not be necessary as one tank will serve the purpose of collecting the filtered water and in turn supply with the backwash water. Hence the actual final set up is as shown below.

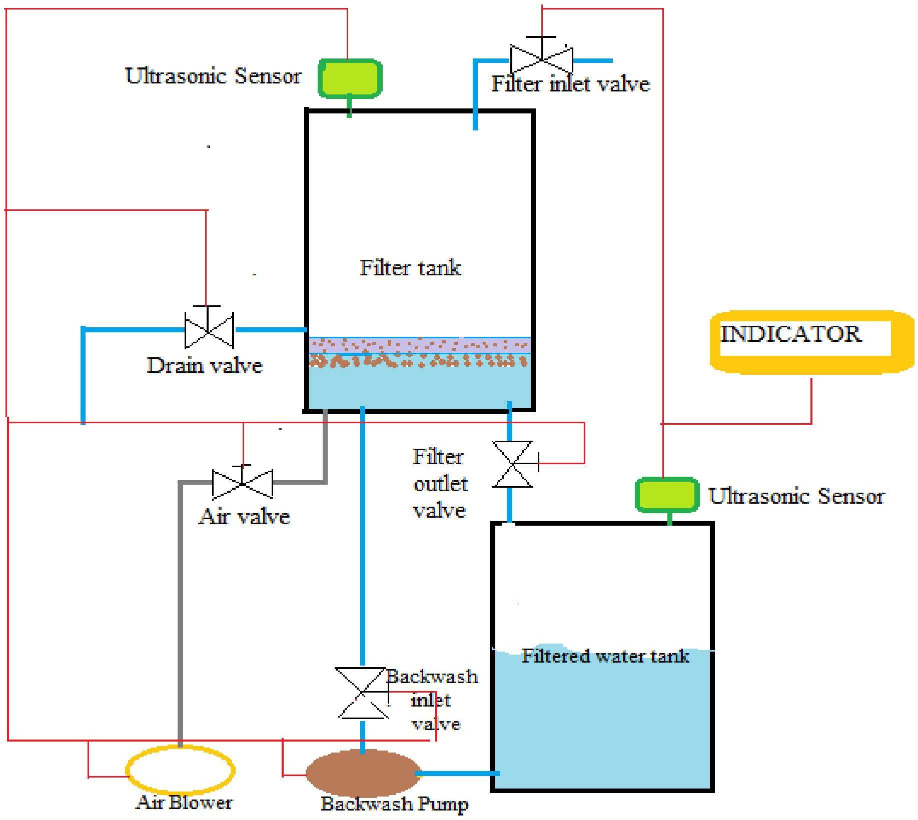


Figure 3.8 – The final Prototype layout

The red lines indicate the control signal from the ultrasonic level sensors.

3.4.1 Principle of Operation

The new setup is almost similar to the previous one hence there is not much change in the way the system operates. The ultrasonic level sensors send their signal to the Arduino controller which in turn give output signals according to the program code as bellow.

- Filter inlet valve opens for as long as the level in the filtered water tank is not high, thus filtration will be in progress.

- Filter outlet valve will also stay open for as long as the backwash process is not in progress.
- Backwash is initiated by the high level in the filter tank which will be a sign of clogged filters.
- The moment backwash is initiated the filter outlet valve closes, backwash pump starts, backwash inlet valve opens, Air blower compressor starts, air valve opens, filter drain valve opens and filter inlet valve closes.
- The backwash process is timed such that it runs for a set time such that it stops once the system has been effectively backwashed.
- This means the blower runs for a shorter time to agitate the mud, the backwash keeps running to flush out the dirty water through the drain valve.

3.5 THE CONTROLS

3.5.1 The control circuit schematic

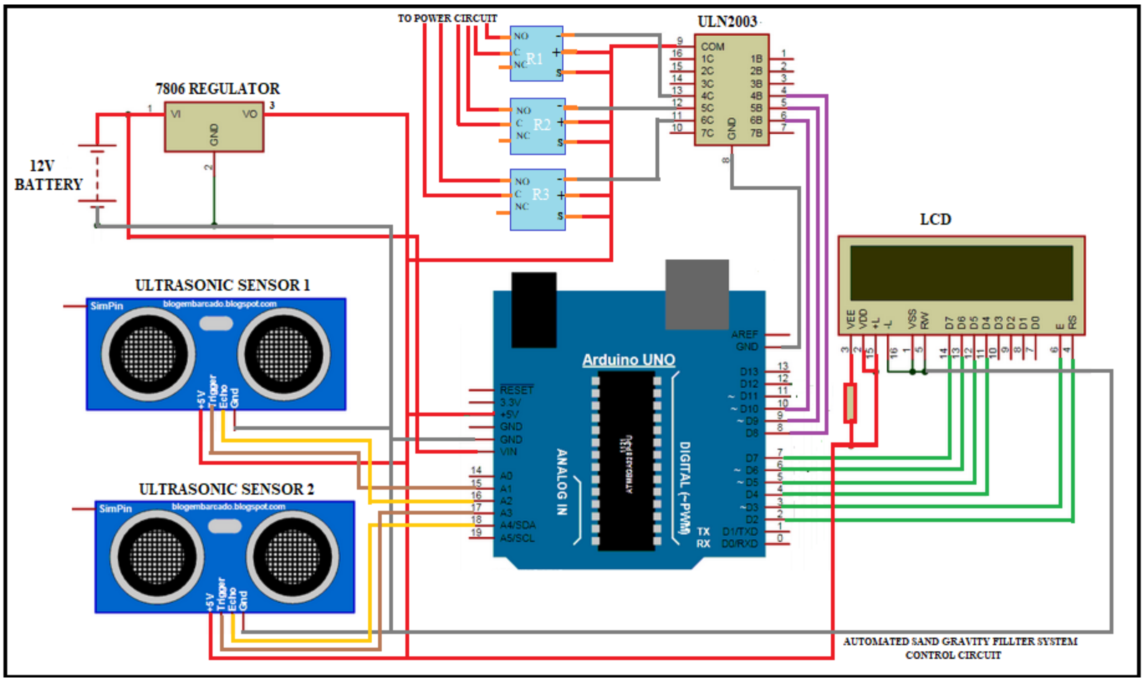


Figure 3.9 – Summarised Control circuit

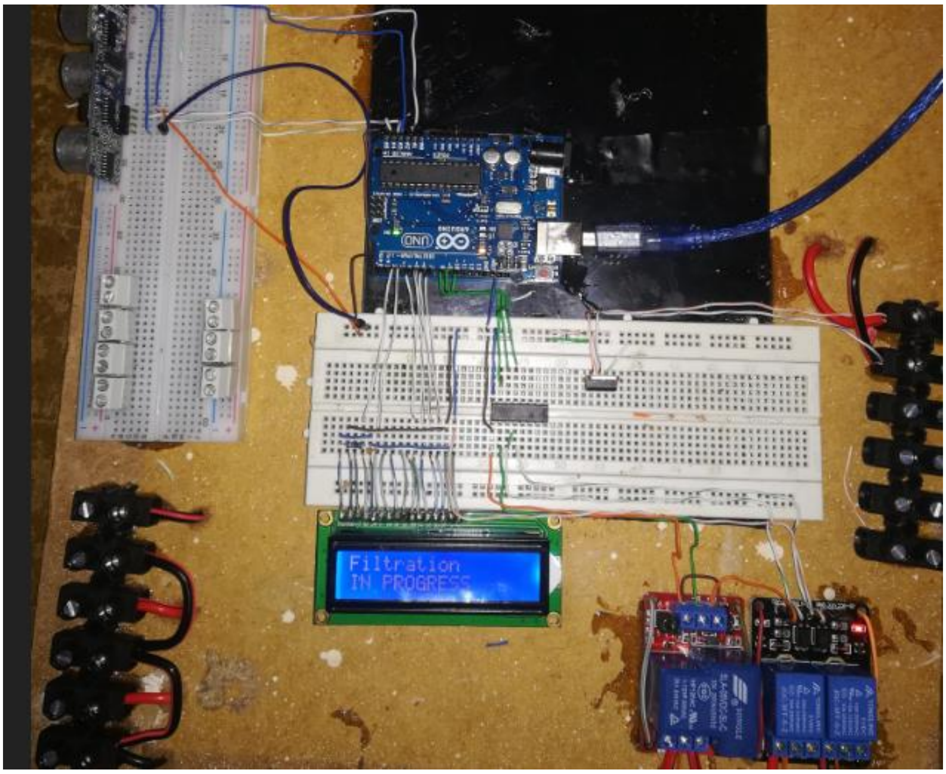


Figure 3.10 – The actual wired control circuit

3.5.2 The Power circuit

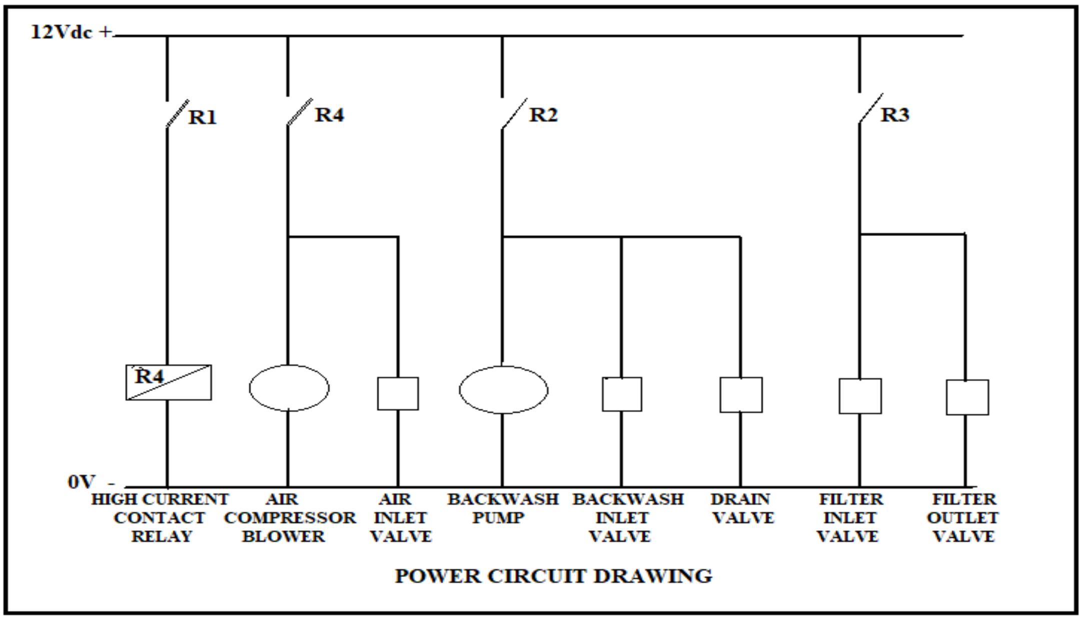


Figure 3.5 – The Power circuit diagram

3.5.3 Circuit and components working principle

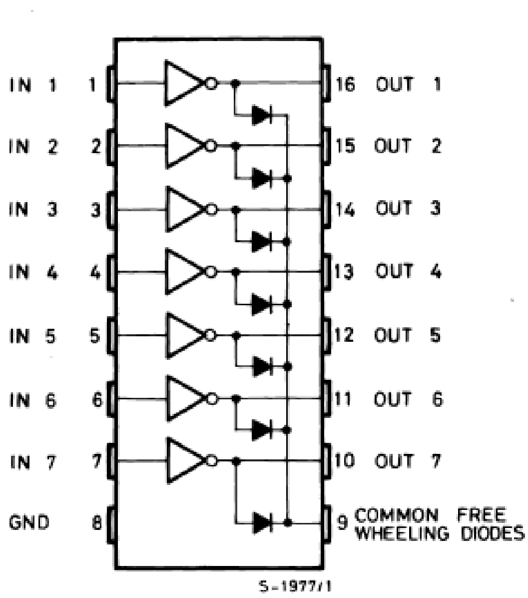
There are components incorporated in to the control circuit and their working principle which is the reason why the researcher chose them is explained below

3.5.3.1 UNL 2003 IC

Initially when the circuit was tested the relays where wired directly from the Arduino outputs. However during the switching on of Solenoid valves, pump and compressor, there is high current flow on the relay contacts and that high current interferes with the signal in the relay coils there buy interrupting the whole control system. Through research a way to block the high current interference was obtained. There are a number of components that can be used but the research found the UNL 2003 IC to be the best and simplest to incorporate in the system.

The ULN2003 is a class of Integrated Circuits (ICs) with high-voltage, high-current Darlington arrays each containing seven open collector Darlington pairs with common emitters. Each channel is rated at 500 mA and can withstand peak currents of 600 mA. Suppression diodes are included for inductive load driving and the inputs are pinned opposite the outputs to simplify board layout [4].

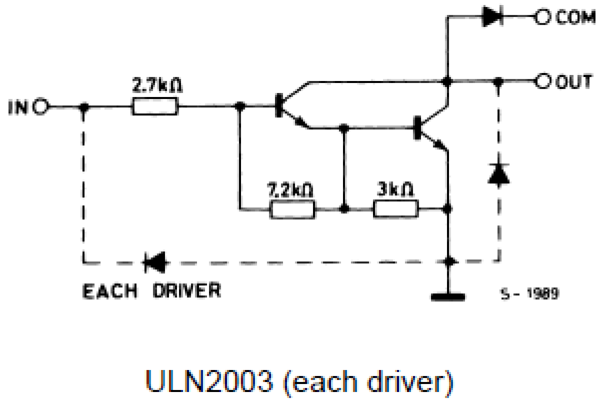
Pin configuration is shown below



[4]

Fig 3.6 – Pin Configuration of a ULN2003 IC

Next is a schematic diagram for each of the seven drivers



[4]

Figure 3.7 ULN driver composition

From the above layout it is clear that when an out pot from the Arduino controller is high, and is fed to which ever driver as its input, when it leaves the driver as an output it will would have been inverted. Hence the output of the driver goes to the negative of the relay. In case of any back current the driver blocks it. Thus, this IC can be used to drive up to 7 relays.

3.5.3.2 Power Supply

For the power of the components the researcher used a 12V DC power source since all our appliances are using a uniform voltage of 12V dc. However our control circuit uses 5v dc hence a 7806 voltage regulator was used. Since from the same 12V power source we will be running other output devices which can cause voltage fluctuations during switching on and off, the 7806 regulator is capable of maintaining a steady uniform output voltage of 6V to the control circuit [5].

3.5.3.3 Ultrasonic Sensor

This is the sensor used for the controls. It measures the distances between the sensor and the level and that is used as our level and is an input to the Arduino controller.

The ultrasonic sensor module uses the phenomenon of echo of sound. A pulse is sent for about a time of 10us to trigger the module. There after the module instantly sends 8 cycles of 40 KHz ultrasound signal and checks its echo. The signal returns back and is captured by the receiver after striking on the targeted object. The following formula is used to calculate the distance the pulse travels.

$$D = c \times \frac{t}{2}$$

Equation 2

Where: D is the distance between sensor and surface of the surface of the substance measured, c is the speed of signal, t is the time taken by the signal to return to the sensor.

The product of speed and time is divided by 2 because the time is the total time it took to reach the obstacle and return back. Hence the time to reach obstacle is just half the total time taken [3] [6].

3.5.3.4 Arduino and LCD

The Arduino is the main controller of the system and as mentioned previously it is the brain of the circuit as it accepts the input signals from the sensors (ultrasonic level sensors in this case) and uses the programmed code to give out put signals on output pins which are used to drive our output devices. The LCD is used for display purposes, in this case the Arduino is coded to give the operator visual display of the process in progress and the level on the Filtered water tank [6].

3.5.3.5. Relays

The relays are used as switching mechanisms to our output devises. Each relay has a normally open and a normally closed contact. The normally open contact closes when a 5V output signal is sent from the controller to energise the relay coil. The opposite happens to the normally close contact. However the relay coils can handle up to a limited amount of current flow, hence for higher current devices like the compressor in this case, the Arduino based relays can be used to switch on a higher current rated relay which will in turn switch on the output device [6].

3.6 CONCLUSION

With the above layout and components came out clearly to demonstrate the actual plant.

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CHAPTER 4

RESULTS AND ANALYSIS

4.1 INTRODUCTION

This chapter reviews the findings of the study based on the results of the prototype. The measurements were made using the ultrasonic sensors positioned on the top of the two tanks and reading on the LCD through the Arduino Controller. A flow was deduced based on the time taken to filter the water while observing the levels on both tanks. A number of test were made before backwashing to observe changes in the filtration rate and there after the plant was automated to see the response as the rate reduced due to clogging of the filters by the suspended matter from the dirty water used. The bases of the results and analysis is based on filtration rate and backwashing time.

4.2 FILTRATION RATE VERSUS UNDER DRAINAGE SYSTEM

During the design of the prototype the researcher observed filtration rate using the under drainage system.

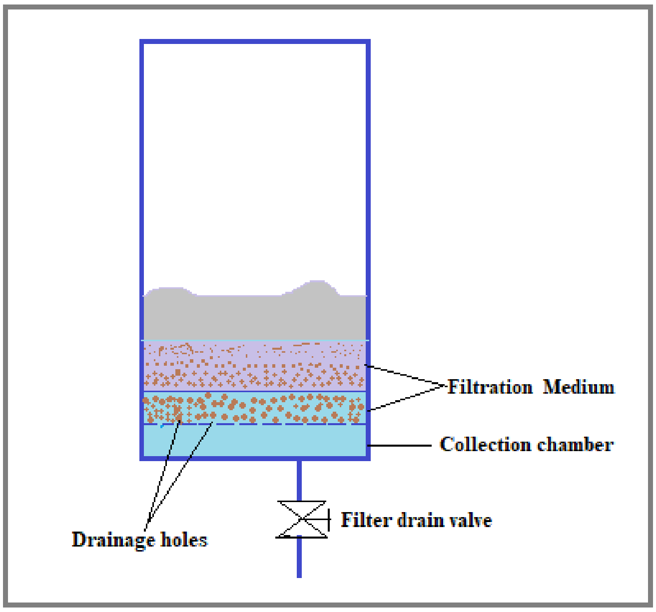

Figure 4.1 – Filter under drainage system illustration

As shown in the above figure, a hint of how a filter under drainage system looks like, the drainage is determined by the number and size of drainage holes, The size of the drain valve and the filter base size. Since the size of the valve (Solenoid valve) used and the base area is fixed, the only variable parameter here was the number and size of drainage holes. Firstly the size of drainage holes is determined by the size of filtration medium at the base, (Recall that the medium with bigger granules is at the base) such that we don't dispose the sand into the collection chamber. Hence the size of the holes was fixed leaving us to play with their number. The number was increased from 10 to 55 in steps of 10 and 5. Satisfactory results were obtained at 50 but 5 were added just for core clearance above the selected rate. Below is a table of results showing the number of holes against level as per prosonic sensors which is in cm. Thus the test were done in periods of 2 minutes a constant filter inlet flow using clean clear water

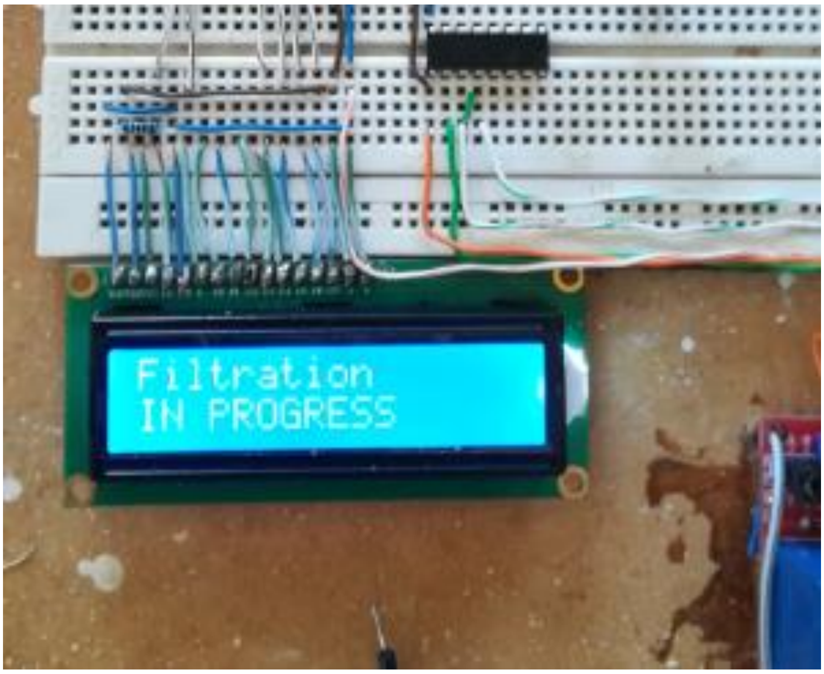

Figure 4.2 – Filtration in progress screen shot

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Indicator reading	Number of holes	Rate per minute (cm)
31	10	3
29	20	5
26	30	8
23	40	11
21	50	13
19	55	15

Table 4.1 – Results of filtration rate vs number of holes

Readings are taken on the basis that the Level indication is shown inversely with the rise. Our empty is at 34 cm. Hence actual level is 34 less indicator reading

4.3 FILTRATION RATE AGAINST LEVEL

The system uses the gravity mechanism hence the level of water in the filter also plays a part in the rate of filtration. Thus this was achieved by maintaining different levels in the filter tank. Below are the results.

Indicator reading (cm)	Filter tank Level	Filtration Rate per minutes (cm)
19	20	15
16	25	18
14	30	20

Table 4.2 – Filtration rate against Level in the filter tank

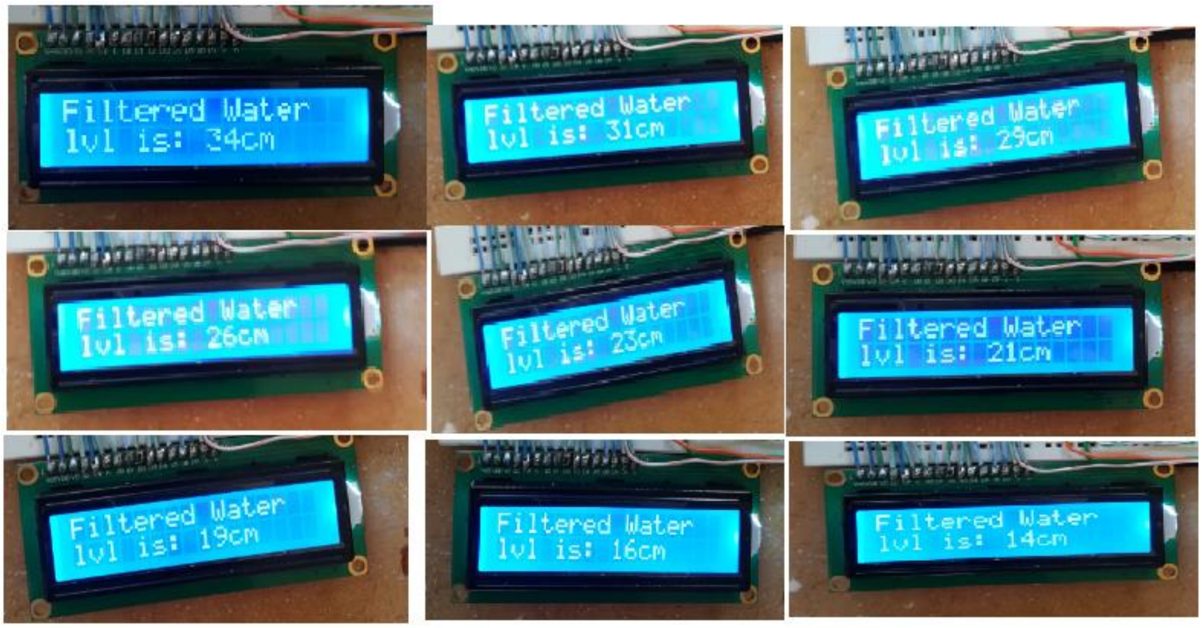

Figure 4.3 – Screen shots of actual results for the above tables

4.3 FILTRATION RATE AGAINST QUALITY OF WATER

Next was to check the effects of the quality of water. At Hwange Power Station the source of water is Zambezi and the quality of water varies with seasons. During the rainy season the water is be muddy and that affects the filtration rate and also the backwashing frequency is affected as the filters get clogged more frequently. While during the dry seasons the water is clear and backwashing frequency is low

Using clear water, filtration rate remained constant at a constant filter fill rate over time but as the water was changed to be muddy the filtration rate decayed exponentially. This leads to the increase of level in the filter tank even with a constant fill rate at the filter inlet. Hence this necessitates the need of backwashing which has to be initiated automatically.

4.4 BACKWASH DURATION AND FREQUENCY.

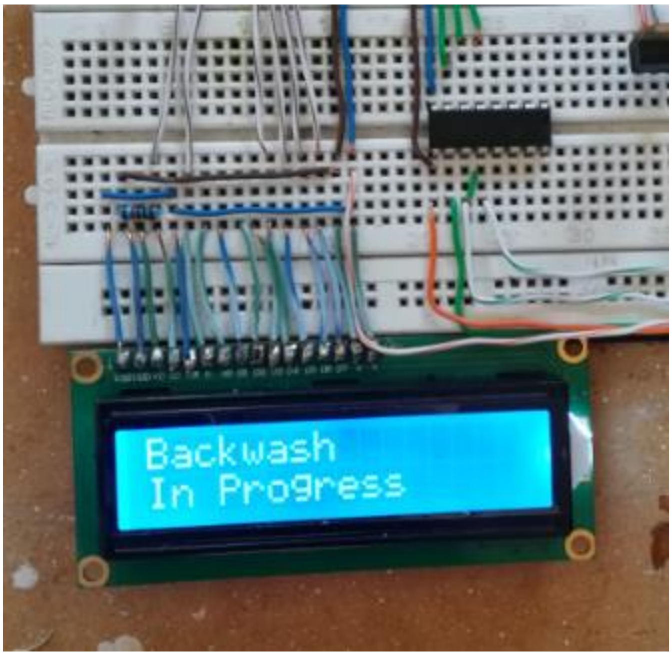

Figure 4.4 – Backwash in Progress screen shot

The frequency of backwash, as observed on the previous result, is determined by the quality of water. The dirtier the water the more the frequency of backwashing the filter for a continuous operation. When the water is not muddy or has less suspended matter in it, then it means longer filtration hours before backwashing and increased water supplies for the next processing stage and end users.

The duration of backwashing can be determined by the pumping rate of the backwash pump and the capacity of the backwash inlet valve, as this is the water used to rinse off the mud and suspended matter through drainage. Nevertheless the duration of backwashing should be long enough to leave the filtration medium clean and also short enough to save the filtered water.

4.5 BACKWASHING PRESSURE

On backwashing the other important factor noted were the pressures of the backwashing water and the blower air into the filter. When they are set to too little they fails to agitate the settled dirty hence failing to serve the purpose, and a minor increase from that can get to a level where they can agitate but can take longer time.

When the pressures are set too high, there is a danger of purging or blowing away filtration medium (Sand) with the dirty water. Since the air and backwash water is fed from the bottom, the filtration medium granules weight due to gravity should sustain the backwashing water and air blower pressures. Therefore these pressures should be high enough to agitate the dirty and achieve filter cleaning within a specified time while should be kept low enough not to blow off the filtration medium.

4.6 RENEWING THE BACKWASHING MEDIUM

After a continuous running of the system the researcher observed that with time the filtration medium (sand) get exhausted and needs to be renewed. Some of the finer granules of sand get washed away with the dirty water during backwashing while part of it escapes into the filter collection chamber meaning there could be somehow some mixing of the filtration medium which takes place. Over a period of time the filtration medium needs to be renewed and the collection chamber cleaned as well. During this renewal process additional sand is required to replace the flashed off sand.

4.7 CONCLUSION

Filtration rate of the sand gravity filter is highly affected by the under drainage system, that is, the more the number of holes the higher the filtration rate and the higher the level in the filter tank the higher the filtration rate. The cleaner the feed water the longer the filtration period before backwashing and the longer the life span of the filtration medium before it is renewed.

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CHAPTER 5

CONCLUSION

After successfully working with the prototype using the Hwange Power Station design and set up it became clear that the model can be implemented with ease in that plant and many other plants with similar models. This prototype demonstrated very well an automated sand gravity filtration system with only one measurement control variable, which is level. There was no starting and stopping of pumps and compressors manually. All was based on the level sensors signals and the program on the controller. Through demonstration of the prototype to the Hwange Power Station Plant operators and other interested parties, they were impressed and recommended that the system be implement in their work place.

RECOMMENDATIONS

Flow, temperature and pressure signals need to be incorporated in the control circuit together with the level signals. We need to monitor the pressure of the Air blower and the output of the Backwash Pump. Also we need to know our flow rates so that we can be able to analyse our system well. We need to monitor air blower and backwash pressures for reasons mentioned in chapter 4, and for the pump we need to make sure that both the suction and discharge pressures are healthy to protect the pump for sucking air that may cause air locks and cavitation of the pump. Temperature control will be used in protecting the pump air blower bearings, hence it is also a necessity to incorporate temperature controls in the system.

A real plant set up can accommodate all these control loops with ease using a PLC that has the capability to also give both discrete (digital) and continuous (analogue) outputs.

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APPENDICES

Arduino Project Code

```
#include <LiquidCrystal.h>

#define trigPin1  A1
#define echoPin1  A2
#define trigPin2  A3
#define echoPin2 A4
const byte pump = 8;
const byte valve1 = 9;
#define valve2  10
#define valve3  11
const byte valve4 = 12;
const byte valve5 = 13;

LiquidCrystal lcd(2,3,4,5,6,7);

long duration, distance, RightSensor, BackSensor, FrontSensor, LeftSensor;
const unsigned long timeout = 1000;
int temp=0;
void setup()
{
 lcd.begin(16,2);
 pinMode(trigPin1,OUTPUT);
 pinMode(echoPin1,INPUT);
 pinMode(trigPin2,OUTPUT);
 pinMode(echoPin2,INPUT);
 pinMode(pump, OUTPUT);
 pinMode(valve1, OUTPUT);
```

```
 pinMode(valve2, OUTPUT);
 pinMode(valve3, OUTPUT);
 pinMode(valve4, OUTPUT);
 pinMode(valve5, OUTPUT);
 lcd.print("  ASF ");
 lcd.setCursor(0,1);
 lcd.print("   System  ");
 delay(2000);
}

void loop()
{
  SonarSensor(trigPin1,echoPin1);
  BackSensor = distance;
  SonarSensor(trigPin2,echoPin2);
  FrontSensor = distance;

  lcd.print(BackSensor);
  lcd.print("-");
  lcd.setCursor(0,1);
  lcd.print(FrontSensor);
  lcd.print("-");
}
void SonarSensor (int trigPin, int echoPin)
{
 lcd.clear();
 digitalWrite(trigPin,LOW);
 delayMicroseconds(2);
 digitalWrite(trigPin,HIGH);
 delayMicroseconds(10);
```

```
digitalWrite(trigPin,LOW);
delayMicroseconds(2);
duration = pulseIn(echoPin,HIGH);
distance=(duration/2) / 29.1;
lcd.clear();
lcd.print("Filtered water");
lcd.setCursor(0,1);
lcd.print("lvl is: ");
lcd.print(FrontSensor);
lcd.print("cm");
delay(2000);
if(BackSensor>15)
{
   digitalWrite(pump, LOW);
   digitalWrite(valve1, LOW);
   digitalWrite(valve2, HIGH);
   digitalWrite(valve3, HIGH);
   digitalWrite(valve4, LOW);
   digitalWrite(valve5, HIGH);
   lcd.clear();
   lcd.print("Filtration ");
   lcd.setCursor(0,1);
   lcd.print("IN PROGRESS");
   delay(5000);
   temp=0;
}

else if(BackSensor<15)
{
  digitalWrite(pump, HIGH);
```

```
  digitalWrite(valve1, HIGH);
  digitalWrite(valve2, LOW);
  digitalWrite(valve3, LOW);
  digitalWrite(valve4, HIGH);
  digitalWrite(valve5, HIGH);
  lcd.clear();
  lcd.print("Backwash");
  lcd.setCursor(0,1);
  lcd.print("In Progress");
  delay(5000);
  temp=0;
 }
}
```