

بسم الله الرحمن الرحيم



SUDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
COLLEGE OF GRADUATE STUDIES

Design and Simulation of a Monitoring and Controlling System for the Cooling Tower of Khartoum North Power Station

تصميم ونمذجة نظام متابعة وتحكم لبرج تبريد محطة الخرطوم بحرى لتوليد
الطاقة

A Thesis Submitted in Partial Fulfillment for the Requirement of the
Degree of M.Sc. In Mechatronics Engineering

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Dedication

I dedicate this research with much love and appreciation to my mother who has always been there for me, to my father who have taught me the carriage and confidence, to my brothers and sister who mean the world to me and finally to my friends, family, colleagues and teachers.

Acknowledgement

Firstly, thanks to Allah, our creator above for being everything and for giving us the ability and strength to complete this research.

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Abstract

Khartoum north power station is a thermal power station that has three phases. Each phase consists of two units with their components, namely, a boiler with auxiliaries, a turbine with auxiliaries, and a generator with auxiliaries. The cooling tower is one of turbine auxiliaries. It is a heat rejection device used to transfer process waste heat to the atmosphere. Make-up water for the cooling tower's reservoir must be supplied under level control. In case of a malfunction of the ball float system the supplied water to condenser will not be regular which may cause a vacuum problem resulting in load instability or even causes the unit to trip. In this research, the ball float system was suggested to be replaced by a level sensor which provides a level signal to a PLC. The PLC controls the motor that operate the supply valve of the cooling tower via the PID control module of the PLC. The optimum control parameters of the PID control module were obtained by trial and error runs of the Simulink module of the MatLab package. The suggested control system was simulated and was found to perform nicely.

مستخلص

محطة الخرطوم بحرى للطاقة هي محطة توليد حرارى تتكون من ثلاث اطوار. كل طور يتكون من وحدتين بمكوناتهما, تحديدًا, القيزان وملحقاته والتوربين وملحقاته والمولد وملحقاته. برج التبريد من ملحقات التوربين وهو جهاز طارد للحرارة يستخدم لنقل الحرارة الغير مفيدة للعمليات الى الجو. ماء التعويض لخزان برج التبريد يجب ان يزود تحت تحكم للمستوى. فى حالة حدوث عطل للعوامة يحدث عدم انتظام للماء الذى يتم تزويده للمكثف مما يسبب انخفاض فى الضغط وعدم انتظام الحمل او حتى خروج التربين عن الخدمة. فى هذا البحث تم اقتراح ان يتم استبدال نظام العوامة بحساس للمستوى. هذا الحساس يزود متحكم منطق مبرمجة باشارة عن المستوى. المتحكم تتحكم فى الموتور الذى يشغل صمام التزويد من خلال الموديول PID للمتحكم. القيم المثلى لبرامترات التحكم للموديول PID تم الحصول عليها اجراء عدة تشغيلات بطريقة المحاولة والتصويب لموديول سيمولينك فى حزمة ماتلاب. تم عمل محاكاة لنظام التحكم المقترح ووجد انه حسن الاداء.

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Chapter one: Introduction

1.1 Preface

Khartoum north power station is a thermal power station that has three phases each consist of two units with their components which consists of a boiler with auxiliaries, a turbine with auxiliaries and a generator with auxiliaries. Cooling tower is one of turbine auxiliaries. It is a heat rejection device used to transfer process waste heat to the atmosphere, it mainly serves the condensers. The major components of the cooling water circuit are:

- 1- A cooling tower which consist of two 3-cell, induced draft fan, cross flow cooling tower of reinforced concrete construction with plastic infill which remove heat by evaporation.
- 2- A cooling tower basin.
- 3- A pump.
- 4- A purge and chemical dosing unit.

Cooling tower basin provide a reservoir of water to insure cooling water circulation for a period without a need for make-up of water lost by evaporation , and also to provide a suction head for pumps drawing the water from the basin. Make-up water must be supplied under level control. The pumps supplies the condenser with cooled water and when the water level is low, make-up water will be supplied to the basin till a certain high level is reached. In case of any malfunction of the system

the supplied water to condenser will not be regular which may cause a vacuum problem resulting in load instability or even causes the unit to trip.

1.2 Problem Statement:

In phase three cooling tower, the current method of measuring and controlling the level is not accurate and affects the performance of the other components. The problem is that the level is controlled using a ball float without any measuring instrument. Ball floats suffer from many problems, it may stick in a certain position or the ball may unplug, or the ball may get drawn resulting in malfunctioning of the water supply system, which may lead to insufficient supply of water to the condense that may cause serious defects that may lead to unit trip.

1.3 Research objectives:

The main goal of the research work is to design a level control system using computer to measure the level of the cooling tower basin and controlling the water supply to it through control transmitter and control valve. By monitoring and controlling the basin cooling tower the stability of the load and generating units will be insured, and also the operator work will be easier, due to process automation.

1.4 Research methodology:

In this research a control system that consists of level transmitter and level control valve to supply the feed water to basin will be designed and simulated. The level transmitter will send a signal to the control valve according to the measurement reading causing it to open or to close as needed. A human machine interface will be designed to facilitate the monitoring of the process. The layout of a thermal power plant is shown in Figure (1.1)

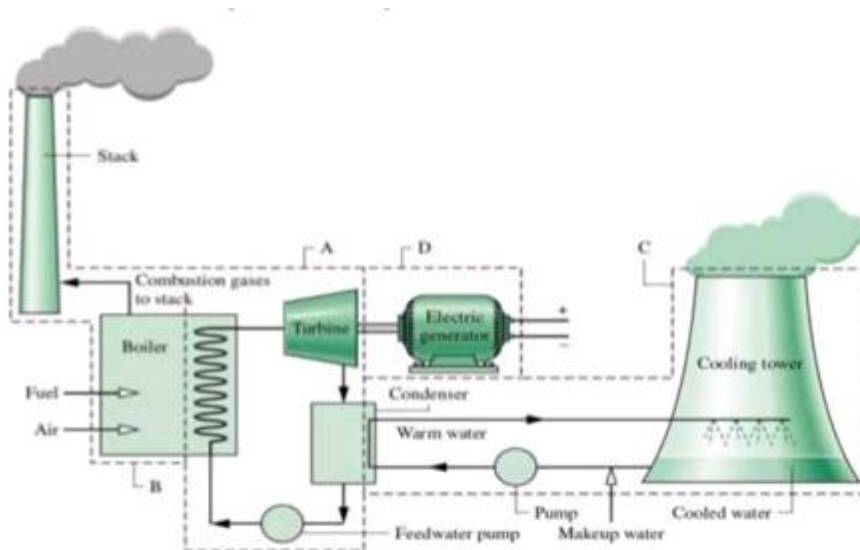


Figure 1.1: The layout of a thermal power plant

Chapter two: Thermodynamics aspects

2.1 Introduction

In this chapter a preview of the thermodynamic aspects of steam power plants will be presented. Rankin cycle is the simplest steam cycle of practical value in steam power plants. In a simple Rankin cycle steam is used as working fluid, generated from saturated liquid water (feed-water). This saturated steam flows through the turbine, where its internal energy is converted into mechanical work to run an electricity generating system. All the energy from steam cannot be utilized for running the generating system because of losses due to friction, viscosity, bend-on-blade etc. Most of the heat energy is rejected in the steam condenser. The feed water brings the condensed water back to the boiler. The heat reject during condensation of steam in the condenser is given away by a sink. As a result of the conversion of much of its thermal energy into mechanical energy, or work, steam leaves the turbine at a pressure and temperature well below the turbine entrance values. Basically the low- pressure steam leaving the turbine at state 2 is first condensed to a liquid at state 3 and then pressurized in a pump to state 4, and this high pressure liquid water is then ready for its next pass through the steam generator to state 1 and is reused around the Rankin cycle again as shown in Figure (2.1).

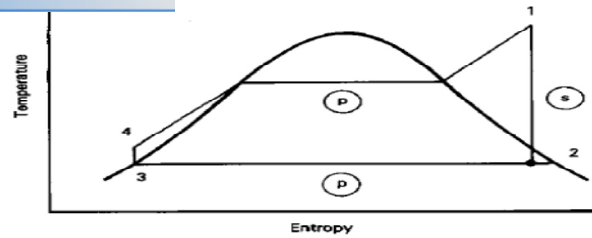


Figure 2.1: The T-S diagram of a simple Rankin cycle

The efficiency of the steam power plant can be improved using Rankin cycle with a super heater, in which the average temperature at which heat is supplied in the boiler can be increased by super heating the steam. Usually the dry saturated steam from the boiler drum is passed through a second bank with smaller bore within the boiler. This bank is situated such that is heated by the hot gases from the furnace until the steam reach the require temperature. The cycle efficiency will increase due to superheating and the improvement in specific steam consumption is even more marked.

2.2 The Steam-Plant Cycle in plant:

The simplest steam cycle of practical value is called the Rankine cycle, which originated around the performance of the steam engine. The steam cycle is important because it connects processes that allow heat to be converted to work on a continuous basis. This simple cycle was based on dry saturated steam being supplied by a boiler to a power unit such as a turbine that drives an electric generator. Dry saturated steam is

at the temperature that corresponds to the boiler pressure, is not superheated, and does not contain moisture. The steam from the turbine exhausts to a condenser, from which the condensed steam is pumped back into the boiler. It is also called a condensing cycle, and a simple schematic of the system is shown in Figure (2.2).

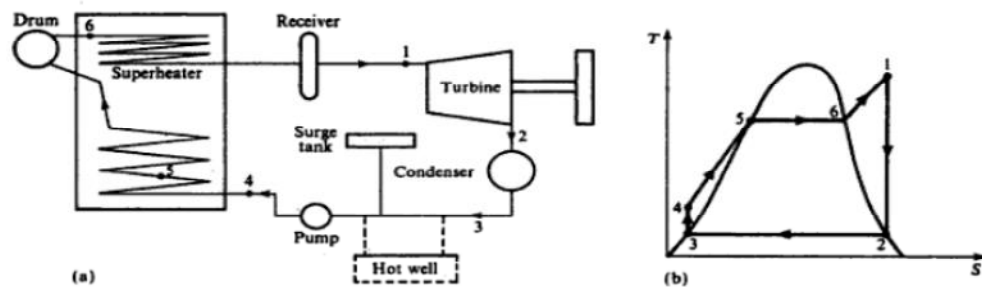


Figure 2.2 Steam plant with a super heater (a) and the cycle on a T-s diagram (b)

2.3 Heat rejection:

The amount of heat rejected from modern thermal power plants is significant in that it represents 60 percent of the total heat input. Of this amount, 10 to 15 percent is rejected out the stack with the flue gas. Most of heat balance (approximately 45 percent) results from the condensing of the exhaust steam from the turbine. Eventually, all this rejected heat is absorbed by the atmosphere, although the heat may first be rejected to a body of water such as a lake, river, or ocean. Heat-rejection systems are generally classified as once-through or closed:

- 1- Once-through systems. Water is withdrawn from a lake, river, or ocean and then pumped through the condenser, where its temperature is

increased by 15 to 20°C. The warmer water is then discharged back to its source. Evaporation from the natural water source to the atmosphere eventually cools this water.

- 2- Closed-loop systems. Heat is rejected to the atmosphere through the use of either a cooling tower or some form of outdoor body of water such as a spray pond or cooling lake.

In many areas, the once-through cooling system is unacceptable for a new power plant. Either the site is already developed and the natural source of water cannot support another plant, or environmental restrictions prevent the use of this system. Therefore, nearly all new power plants use the closed-loop system for heat rejection and incorporate a cooling tower. Cooling ponds and lakes are found primarily at existing sites.

In wet cooling tower systems, cooling water is circulated through the condenser and absorbs heat from the exhaust steam from the turbine. The heated cooling water is then circulated through a cooling tower, where the absorbed heat is rejected to the atmosphere by the evaporation of some of the circulating water. The cooled water is then returned to the condenser by a circulating water pump. Makeup water must be provided to replace the water lost during evaporation and during blow down, where contaminants are controlled.

The cooling tower therefore performs the following major functions:

- 1- Removes the heat that the cooling water absorbed in the condenser

2- Minimizes the use of cooling water

3- Provides cooling water to the condenser to obtain high plant thermal efficiency

2.4 Khartoum North Thermal Power Station

Khartoum North Thermal Power Station (KNPS), with an installed capacity of 380MW, ranks as the second biggest thermal power plant in Sudan , The power plant comprises of 6 generating units (two 30MW per unit and two 60 MW per unit and two 100 MW per unit). Construction of the plant began in March 1981. The first two unit were commissioned in 1985 and the construction for the next two at august 1988 and commissioned at 1992, the construction for the last two units began at 2006 and were commissioned recently in April 2010

The plant uses heavy fuel from the Algaily Refinery and Alobyed Refinery, and water from the Blue Nile River. The water is processed in a plant outside the station called river side, where it go through many chemical treatments to purify it, so it can be used in the main plant .

In the plant the water from river side received to two destination one received in Demineralization Station where chemically processed to used in the boiler, and other destination is the cooling tower through the dosing plant in which chemical dosing add to the water for more purification after that it called make p water and through the control valve delivered to the cooling tower basin to be cooled and send to condenser and the many different coolers in the power plant, The

turbine manufacturers for the KNPS Thermal Power Station include British and Chinese companies and so as the boilers, generators and its auxiliaries.

2.4.1 The thermal power plant

Khartoum North Thermal Power Station operates using a closed steam power cycle, where water undergoes various thermodynamic processes in a cyclic process. The boiler plant involve in the cycle feed water is supplied to boiler drum, where water is boiled and converted into dry saturated steam , which is further superheated in the super heater and then fed to HP cylinder of the turbine. The steam expands in the turbine giving up heat energy, a high proportion of which is transferred into work energy on the turbine shaft. The shaft is coupled to an electrical generator, which produces electrical power. Steam leaving the HP turbine returns to the boiler, where it is reheated. The reheated steam is further expanded in the LP turbines, before passing into the condenser.

In the condenser, which is the large surface type heat exchanger, the steam is condensed by transferring its latent heat of vaporization to cooling water (CW), the main steam, have been condensed in the condenser, is now in a liquid state at a very low pressure and approximately saturation temperature .This water drain from condenser, where it enters the hot well. The water in

the hot well is pumped by the condensate structure pump through the low pressure feed heating system to another pump, the boiler feed pump.

In a modern regenerative cycle, some of the steam passing through the turbine cylinders is bled from a series of extraction belts located after selected moving blade stages and fed to the condensate and feed water heaters. This steam is used to heat the condensate in the LP heaters and the feed water in the HP heaters, which are of a surface type.

The boiler feed pump increase the water pressure to a level in excess of the drum pressure , to provide for the pressure loss in the boiler circuit and HP feed heating train , the cycle is now complete.

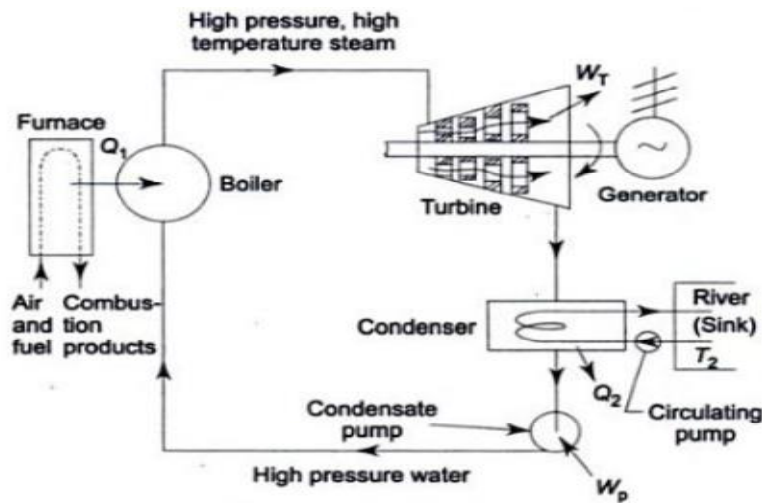


Figure 2.3 a schematic diagram of a simple steam power plant

Figure 2.3 shows a schematic diagram of a simple steam power plant working on the vapor power cycle. heat is transferred to water in the boiler from external source (furnace, where fuel is continuously burnt) to raise steam, the high pressure high temperature steam leaving the boiler expands in the turbine to produce shaft work, the steam leaving the turbine condenses into water in the condenser (where cooling water circulates, rejecting heat and then the water is pumped back to boiler.

2.4.2 Power plant cycles and cooling plant:

In Khartoum north power station, generating electric power from steam power plant go through many cycles as followed:

- 1- Fuel Oil system
- 2- Water transmission and treatment consist of:
 - 2-1 River side work
 - 2-2 Station Clarified
 - 2-3 Demineralization Station
- 3- Feed water cycle
- 4- Steam Cycle
- 5- Air cycle
- 6- Lubrication Cycle
- 7- Cooling Cycle
- 8- Close Circuit Cooling Water
- 9- Aux. Steam

The cycle of the research subject is the cooling cycle, this cycle condensate the superheated steam after moving through the turbine and entering the condenser ,also cooling the lubrication oil that lubricate the moving parts of the turbine , and cool the water for the closed circuit cooling water ,this circuit cool the lubricant oil and the working oil and the mechanical seal in the boiler feed water pump , close circuit also cool the service air compressor and the compressor in the chemical sampling station , and cool the bearing of the rotary air heater and forced draft fan. The cooling cycle also cool the air that used to cool the generator aka generator air cooler.

The cooling cycle consists of a cooling tower in which hot water enter to it through two riser and through the cooling tower cells hot water is collected in the basin and while it came down to basin it is cooled through the fans that is installed on the top of the tower. The fans draw the cool atmosphere air through the side holes, the cold water is then drawn from the basin by cooling water pumps – two pumps / unit one on service and other standby – to the condenser, generator air cooler, to lubrication air cooler and close circuit cooling water, the hot water collected from the all mentioned equipments to one main line and return to the cooling tower, and the cycle continue. An illustration of a typical condenser is shown in figure (2.4).

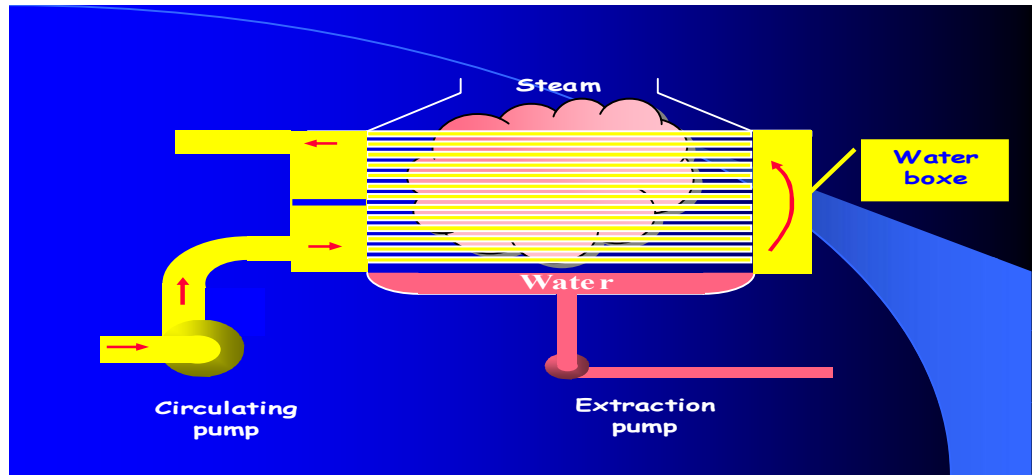


Figure 2.4: An illustration of a typical condenser

2.4.3 Phase 3 cooling tower

Phase three cooling tower type is Reverse flow mechanical extracted air , Structure type is Reinforced concrete Structure , In cooling tower, Induced draft mechanical cooling tower by means of a cooling tower that relies on the air fan on top of it to induce air forcefully the temperature of hot water is reduced by vaporizing and contact radiation, the Cooling principle In cooling tower is that the temperature of hot water is reduced by vaporizing and contact radiation and its Counter-flow cooling tower by mean of the stuffing of which the water is from top to bottom and air from bottom to top , Stuffing is a kind of device which makes the hot water sprayed by water distribution system - that distributes inlet hot water on the top of stuffing, and it is



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composed of tube and sprayer - in form of water film or drip to increase the contact area and time of as much as possible.

Chapter three: Cooling towers

3.1 Introduction

All new power plants use the closed-loop system for heat rejection and incorporate a cooling tower. The cooling tower is the simplest type of closed-loop system; the circulating water is pumped into a basin, where it provides water storage in addition to the cooling. The cooling water flows through piping and then vertically from the spray to form the shape of an inverted

In wet cooling tower systems, cooling water is circulated through the condenser and absorbs heat from the exhaust steam from the turbine.

The heated cooling water is then circulated through a cooling tower, where the absorbed heat is rejected to the atmosphere by the evaporation of some of the circulating water. The cooled water is then returned to the condenser by a circulating water pump. Makeup water must be provided to replace the water lost during evaporation and during blow down, where contaminants are controlled.

The cooling tower therefore performs the following major functions:

- 1- Removes the heat that the cooling water absorbed in the condenser
- 2- Minimizes the use of cooling water
- 3- Provides cooling water to the condenser to obtain high plant thermal Efficiency

3.2 Types of cooling towers

Cooling towers are special direct-contact heat exchangers where the warm cooling water from the condenser is brought into direct contact with the relatively dry air. The heat-transfer rate depends on maximizing the contact area between the water and air and the length of time for this contact.

All cooling tower designs have the following common features:

- 1- An air circulation system
- 2- A water distribution or spray system
- 3- Packing or fill to maximize the contact between the water and air
- 4- A cooling water collection and discharge basin
- 5- Mist eliminators that minimize droplet carry-over and water loss

Cooling towers are generally configured with the air and water in a counter flow or cross-flow arrangement. In counter flow units, water falls down through the fill while the air moves upward. In cross-flow units, water cascades downward while the air moves horizontally, which is perpendicular to the water flow? These cooling towers are generally classified by the method used to move the air. These are commonly known as (1) mechanical-draft units and (2) natural-draft or hyperbolic units.

3.2.1 Mechanical-draft cooling towers:

Mechanical-draft cooling towers use either single or multiple fans to provide a known volume of air through the cooling tower. Therefore,

then thermal performance is generally more stable and is affected by fewer air variables than natural draft cooling towers. Mechanical-draft cooling towers are either forced draft or induced draft

- 1- Forced draft. The fan is located in the ambient air stream entering the cooling tower, and the air is blown through the unit as shown in Fig 3.1.
- 2- Induced draft. The fan is located at the exit of the airflow and draws air through the tower as shown in Fig 2.2.

Forced-draft mechanical-draft towers are characterized by high air entrance velocities and low exit velocities. Therefore, they are extremely susceptible to recirculation and are considered to have less performance stability than the induced-draft tower. In addition, when plant sites are located in cold weather climates, since the fans are located in the cold ambient air stream (shown in Figure (3.1)), the fans can become subject to severe icing with resulting imbalance. As a result, these fans are often located in a specially designed enclosure to prevent this.

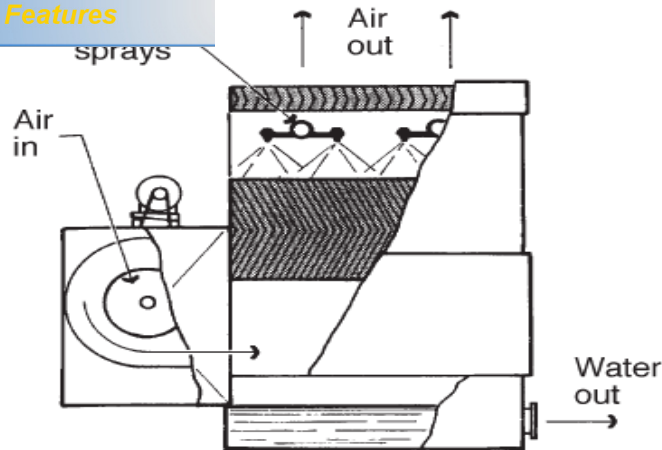


Figure 3.1 Schematic of a forced-draft mechanical-draft cooling tower.

Fans on mechanical induced-draft towers are not subject to recirculation and therefore are more stable. Their location within the warm air stream also provides protection against the formation of ice. These advantages lead to the widespread use of mechanical induced-draft towers.

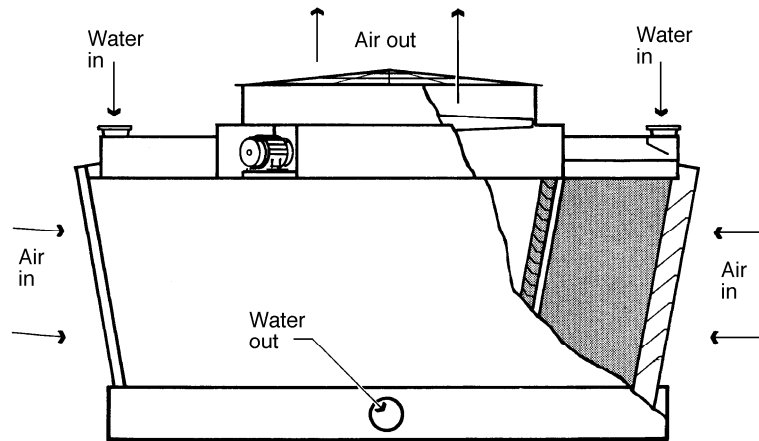


Figure 3.2 Schematic of an induced- draft mechanical-draft cooling tower

Mechanical-draft cooling towers also can be classified by their shape, either rectilinear or round towers. Figure 3.3 shows towers that are

constructed in cellular fashion, and these have been increased linearly to the length and number of cells necessary to meet the required thermal performance.

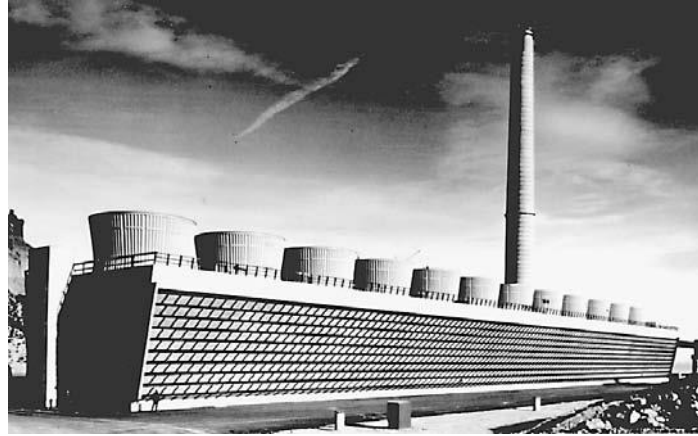


Figure 3.3 Multi cell cross-flow mechanical-draft cooling tower in a rectilinear shape

Two configurations of round towers are shown in Fig 3.4 and 3.5 with fans clustered as close as practicable around the center point of the tower. These tower arrangements can handle large heat loads but with considerably less site area requirements than multiple rectilinear towers.

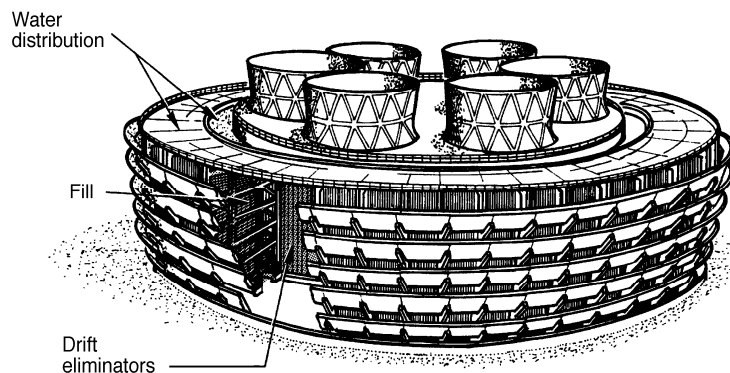


Figure 3.4 Multi cell mechanical-draft cooling tower in a round shape

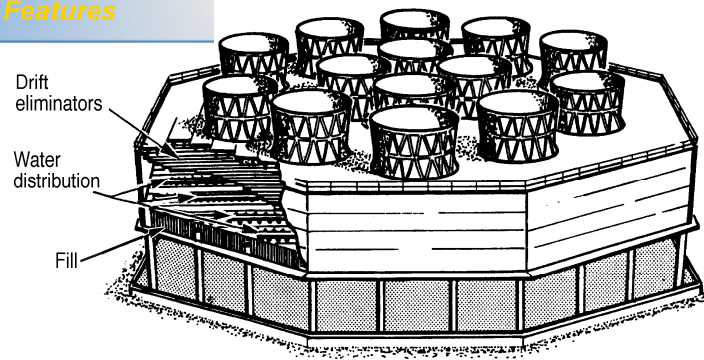


Figure 3.5 Multi cell mechanical-draft cooling tower in an octagon shape

A double-flow-principle mechanical-induced-draft tower shown in Figure 3.6, the double-flow tower consists of two identical sections divided at the tower center by a partition that extends from the water level in the basin to a point close to the fan inlet housing. The housing consists of vertical columns made from sturdy timbers that are spaced on close centers for added strength. The vertical members are supported mechanically by bracing to provide rigidity where required. Transverse bracing as well as longitudinal bracing is provided to give maximum strength.

To avoid the corrosive influences to which cooling towers are subjected by water conditions and atmospheric contamination, moldings are made of glass-reinforced polyester. Structural-ceramic rings are applied in conventional connector-ring joints where values exceeding those available in bolted joints are required. The ceramic rings are made of complex porcelain. This construction and use of materials eliminate the possibility of bearing failure in the wood under the inroads of rot in a rust-deposit area. Cement board covers much of the exterior of the

tower, the covering including end-wall casings and board louvers that form the tower sides. This adds to fire safety and structural sturdiness.

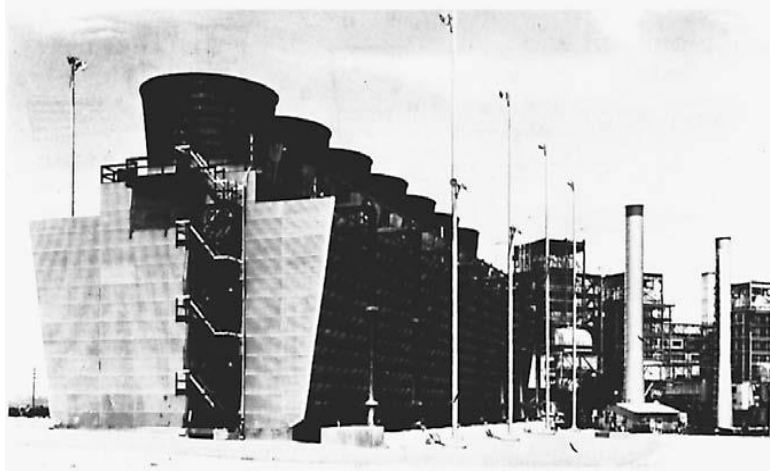


Figure 3.6 Double-flow induced-draft mechanical-draft cooling towers

The material under each “section” is filled with splash bars set in fiberglass supports, which are impervious to all corrosive conditions. These high-strength grids are on close centers so that there can be no sagging fill or channeling of water flow. Splash bars are securely retained without nails or other corrosive fasteners and can elongate or shrink without distortion or cracking. Between the filling and the center longitudinal partition are herringbone drift eliminators for removing water entrained in the air. The drift eliminators also function as effective diffusers, equalizing pressure through the cooling chamber.

For large fans, blades of glass-fiber-reinforced polyester are used to eliminate corrosion. Aluminum blades are also available. The gear reducer contains an enclosed lubrication system with a renewable cartridge filter. The use of glass-fiber-reinforced grid supports and

morning together with the method of construction eliminates corrosion or degradation effects resulting from contaminants in the circulating water; therefore, there is no galvanic corrosion or rusting, as occurred with ferrous parts in the past. Structural-ceramic rings are applied in conventional connector-ring joints; the ceramic material is porcelain. The combination of the foregoing reduces deterioration by corrosion regardless of the presence of acid, caustic, salt, or other contaminants in the circulating water. Water treatment for the circulating water is also commonly used to minimize corrosion. Directly over the center of the tower are located the induced-draft fans. The motors are removed from the airstream and set outside the fan housing. The louvered openings are on the side through which the air is drawn. Across the top of the tower are the open-distribution hot-water basins. The bottom of each basin contains a series of porcelain nozzles that are placed to provide uniform water distribution to the “filling” below. Flow-control valves are provided for each tower and are used to vary the flow if desired. In the center of the fan housing is the fan assembly with gear-reducer drive and flexible-drive shaft. Two-speed motors are available for low-load operation. The level is held constant by automatic-control float makeup valves to replenish the water supply by automatic control of the blow down from the basin and by the overflow pipe to the drain. If well designed, the water-distribution system should be readily accessible for regulation of flow and for cleaning and inspection. With the double-flow tower, one-half of any cells may be shut down while the other half remains in service. Large cooling towers are usually provided with

concrete basins. These basins should be watertight and deep enough to store an adequate amount of water. Sufficient space and clearance should be permitted for ease in cleaning and painting. Access doors should be conveniently located and large enough to permit equipment that is necessary for repairs and maintenance to be moved into the tower's interior.

In designing and locating a cooling tower, consideration should be given to the prevailing wind direction and to any obstructions surrounding the tower, since any interference will reduce the efficiency of operation and influence the performance. Cooling towers must be designed and built to support their own weight, together with the weight of the water and the force produced by the wind. Standard wind pressure design is 30-psi wind load, though in certain areas where wind storms prevail, additional safeguards must be taken to withstand loading. Wood towers are to be recommended over steel towers to avoid corrosion. If bolts are used, they should be bronze or galvanized. Nails are never used to carry a load. Consideration should be given to fire prevention, to proper access to facilities, and to walkways for adjustments, servicing, and maintenance.

3.2.2 Natural-draft hyperbolic cooling towers:

The natural-draft hyperbolic cooling tower shown in Figure 3.7 utilizes airflow that is produced by the density differential that exists between the heated air inside the tower, which is less dense, and the relatively

cool ambient air outside the tower, which is denser. This density differential is such that no fans are required because natural draft results. These types of cooling towers tend to be quite large, since they often handle large quantities of cooling water, 250,000 gpm and greater. Because of the relatively small temperature and density differences of the inside and outside air, these cooling towers are generally very tall, in the range of 300 to 500 ft high.

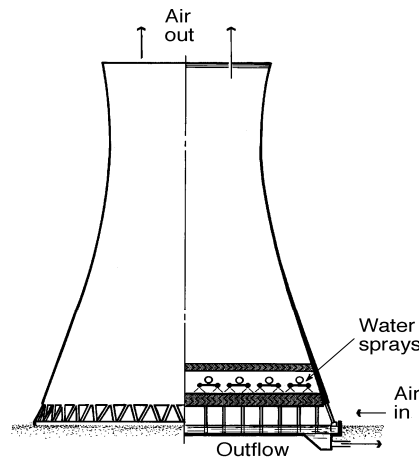


Figure 3.7 Schematic of natural draft hyperbolic cooling tower

The shape of the tower shell is hyperbolic, thus the name of this type of cooling tower. This shape has little effect on the natural-draft capabilities, but it offers superior strength and resists wind loads and therefore requires less material than other designs, thus being more cost-effective.

Natural-draft cooling towers operate most effectively in areas that have a higher humidity as compared with plants located in an arid region or one located at a high altitude. Such plant sites would most probably use

mechanical-draft cooling towers or possibly an air-cooled condenser system. Hyperbolic cooling towers are more expensive than mechanical-draft cooling towers, and they are used extensively in large utility power plants. However, because of their lower operating cost as a result of no fan power requirements, the overall costs over the plant life are lower which justifies the higher initial capital cost. For any plant design, a careful evaluation of the initial capital costs and the operating and maintenance costs must be made of the various designs when the plant size is such that natural-draft towers are known to be a possibility an illustration of a hyperbolic natural-draft cooling tower is shown in Fig 3.8. This unit is part of a 265-MW power plant and handles 120,000 gpm of cooling water from 110 to 87°C. It has a diameter of approximately 130 ft at the top and 245 ft at the bottom and is 320 ft high.



Figure 3.8 Hyperbolic natural-draft cooling tower

3.3 Design considerations

There are several design considerations that should be incorporated into a cooling tower design, whether it is a mechanical- or natural draft tower:

- 1- Tower fill or packing. Cooling tower fill, which is often called packing, is one of the most important components of the cooling tower. Its purpose is to increase the contact area between the air and water, as well as the water residence time. Fill is generally classified as film type or splash type:
 - a- Film-type fill this design allows a thin water layer to be directed along a plate or sheet, and air is forced past the water. Several plates are placed together at fixed angles in order to maximize the air-water contact area and the water residence time.
 - b- Splash-type fill by inducing a splashing action, the air-water contact area and the water residence time are increased. In these units, water enters the tower and falls on the splash bars, which divide the large water droplets into smaller ones and thus increase the surface area. The bars also slow the fall of the droplets, which increases the residence time. The materials used for splash bars are fiberglass, PVC (plastic), and redwood.
- 2- Fire protection. There is the potential for fire on cooling towers especially when wood or other combustible materials are used. Wood towers are susceptible to fire after they have been out of

operation for a period of time, which would allow them to dry out. In order to provide protection, designs incorporating wood have fire-protection systems as part of their design. In fact, during construction, the plant's fire-protection system must be operational to protect against the possibility of fire as a result of welding operations, etc. With the use of more noncombustible material such as PVC and concrete, approval of designs without a fire-protection system has been granted.

Closed-loop systems. Heat is rejected to the atmosphere through the use of either a cooling tower or some form of outdoor body of water such as a spray pond or cooling lake.

Chapter Four: Level Measurement

4.1 Introduction

Once we measure the quantity we are interested in, we usually transmit a signal representing this quantity to an indicating or computing device where either human or automated action then takes place. If the controlling action is automated, the computer sends a signal to a final controlling device which then influences the quantity being measured. This final control device usually takes one of the following forms:

- 1- Control valve (for throttling the flow rate of a fluid)
- 2- Electric motor
- 3- Electric heater

Both the measurement device and the final control device connect to some physical system which we call the process. As shown in the general block diagram of the process in figure (4.1):

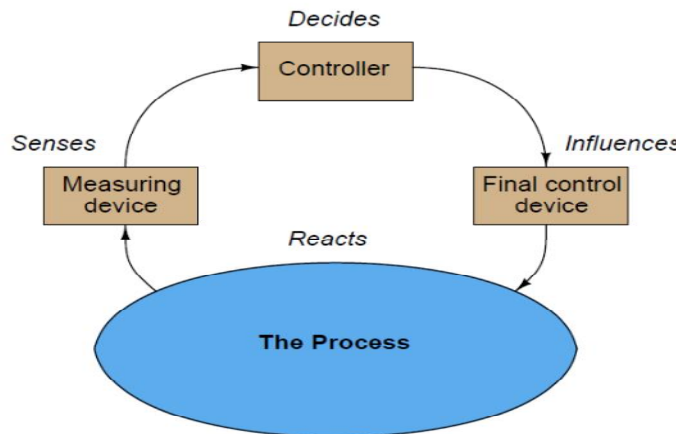


Figure 4.1: the general block diagram of a process

A wide variety of technologies exist to measure the level of substances, each exploiting a different principle of physics. The major level-measurement technologies in current use are the following:

4.2 Level gauges (sight glasses):

Level gauges are perhaps the simplest indicating instrument for liquid level in a vessel.

4.2.1 Basic concepts of sight glasses:

The level gauge or sight glass is to liquid level measurement a very simple and effective technology for direct visual indication of process level. In its simplest form, a level gauge is nothing more than a clear tube through which process liquid may be seen. The following photograph shows a simple example of a sight glass:



Figure 4.2 simple example of a sight glass

A functional diagram of a sight glass shows how it visually represents the level of liquid inside a vessel such as a storage tank:

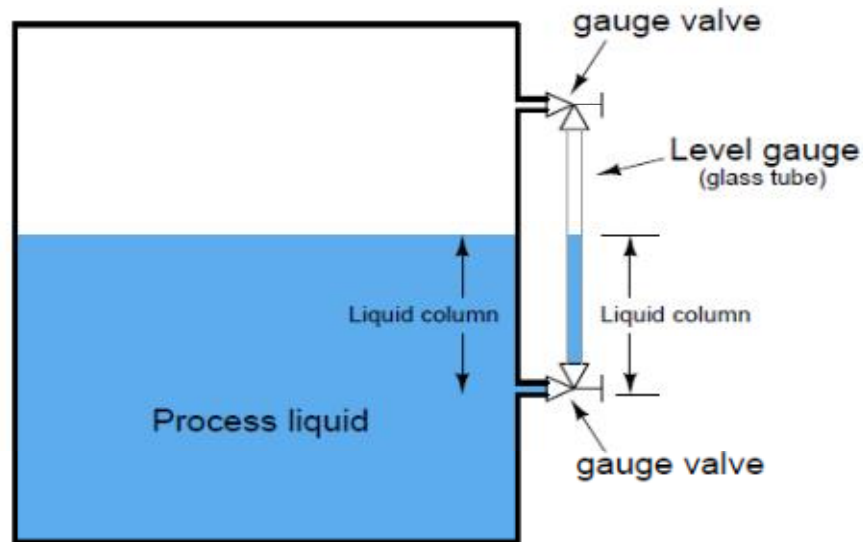


Figure 4.3 functional diagram of a sight glass

Level gauge valves exist to allow replacement of the glass tube without emptying or depressurizing the process vessel. These valves are usually equipped with flow-limiting devices in the event of a tube rupture, so too much process fluid does not escape even when the valves are fully open.

4.2.2 Interface problems

As simple and apparently trouble-free as level gauges may seem, there are special circumstances where they will register incorrectly. One such circumstance is in the presence of a lighter liquid layer existing between the connection ports of the gauge. If a lighter (less dense) liquid exists above a heavier (denser) liquid

in the process vessel, the level gauge may not show the proper interface, if at all:

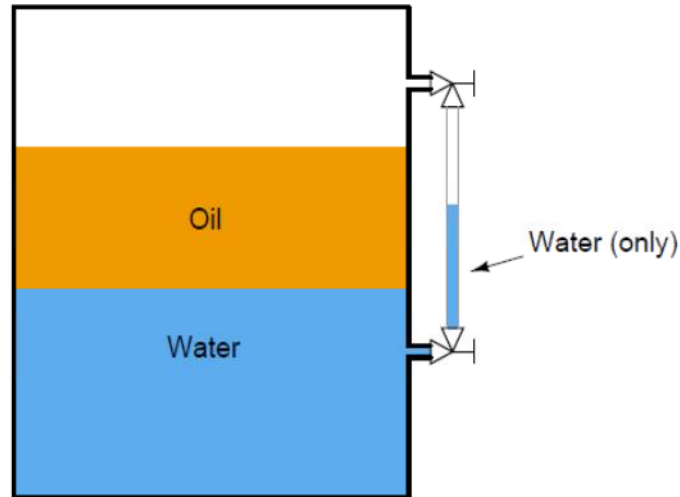


Figure 4.4 sight glasses Interface problem

Since the oil lies between the two levels gauge ports into the vessel (sometimes called nozzles), it cannot enter the sight glass tube, and therefore the level gauge will continue to show just water.

The only way to ensure proper two-part liquid interface level indication in a sight glass is to keep both ports (nozzles) submerged:

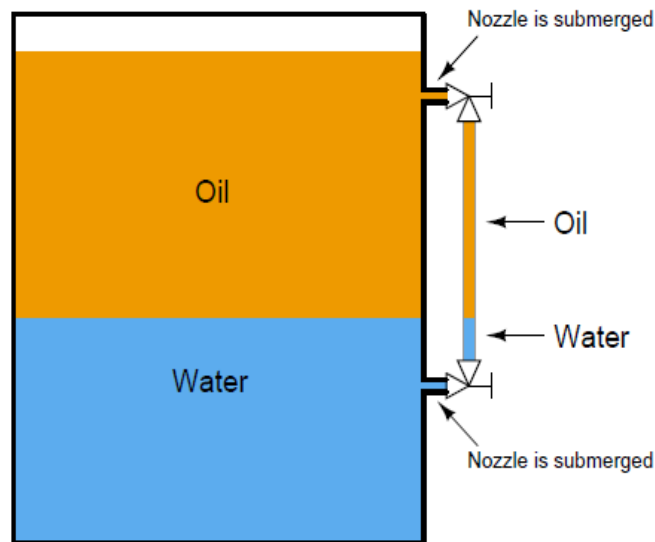


Figure 4.5 sight glass with both ports submerged

4.2.3 Temperature problems:

Another troublesome scenario for level gauges is when the liquid inside the vessel is substantially hotter than the liquid in the gauge, causing the densities to be different. This is commonly seen on boiler level gauges, where the water inside the sight glass cools off substantially from its former Temperature inside the boiler drum:

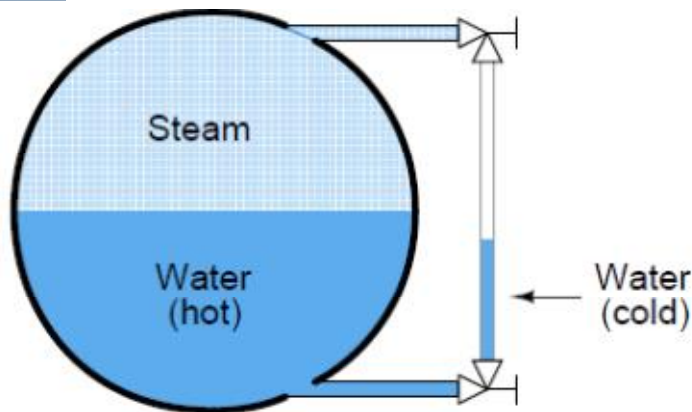


Figure 4.6: Temp problem

Looking at the sight glass as a U-tube manometer again, we see that unequal-height liquid columns may indeed balance each other's hydrostatic pressures if the two columns are comprised of liquids with different densities. The weight density of water is 62.4 lb/ft³ at standard temperature, but may be as low as only 36 lb/ft³ at temperatures common for power generation boilers.

4.3 Float

Perhaps the simplest form of solid or liquid level measurement is with a float a device that rides on the surface of the fluid or solid, the float itself must be of substantially lesser density than the substance of interest, and it must not corrode or otherwise react with the substance.

Using a small winch controlled by a computer – having the computer automatically lower the float down to the material surface and measure the amount of cable played out at each measurement cycle

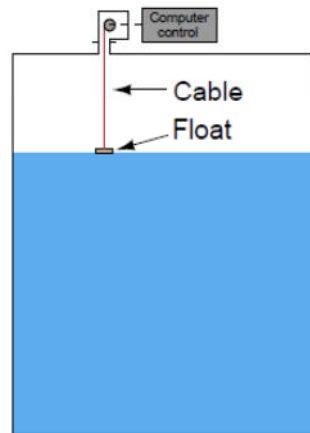


Figure 4.7: Float level measurement

A simpler version of this technique uses a spring-reel to constantly tension the cable holding the float, such that the float continuously rides on the surface of the liquid

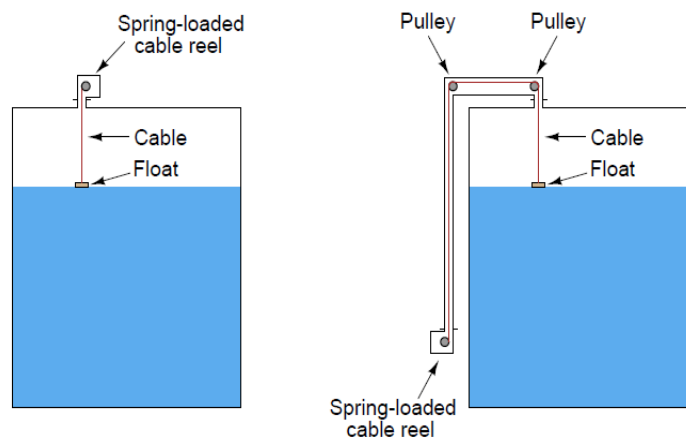


Figure 4.8 Float level measurements with spring-reel

The following photograph shows the “measurement head” of a spring-reel tape-and-float liquid level transmitter, with the vertical pipe

housing the tape on its way to the top of the storage tank where it will turn 180 degrees via two pulleys and attach to the float inside the tank



Figure 4.9 measurement head of a spring-reel tape-and-float liquid level transmitter

The spring reel's angular position may be measured by a multi-turn potentiometer or a rotary encoder (located inside the "head" unit), then converted to an electronic signal for transmission to a remote display, control, and/or recording system. Such systems are used extensively for measurement of water and fuel in storage tanks, if the liquid inside the vessel is subject to turbulence, guide wires may be necessary to keep the float cable in a vertical orientation

One of the potential disadvantages of tape-and-float level measurement systems is fouling of the tape (and guide wires) if the substance is sticky or unclean.

A variation on the theme of float level measurement is to place a small float inside the tube of a sight glass-style level gauge



Figure 4.10 theme of float level measurement

4.4 Hydrostatic pressure:

A vertical column of fluid generates a pressure at the bottom of the column owing to the action of gravity on that fluid. The greater the vertical height of the fluid, the greater the pressure, when all other factors being equal. This principle allows us to infer the level (height) of liquid in a vessel by pressure measurement.

A vertical column of fluid exerts a pressure due to the column's weight. The relationship between column height and fluid pressure at the bottom of the column is constant for any particular fluid (density) regardless of vessel width or shape.

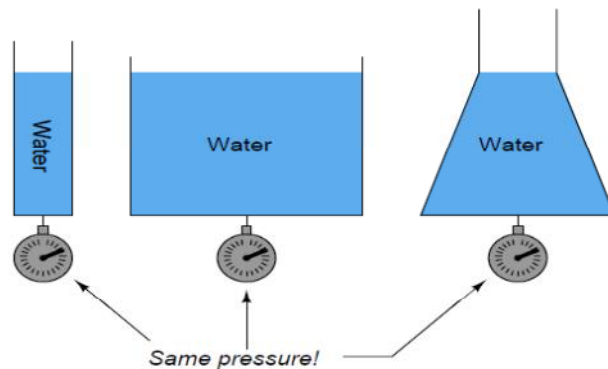


Figure 4.11 Hydrostatic pressure level measurements

The mathematical relationship between liquid column height and pressure is as follows:

$$P = \rho gh \dots (1-4)$$

$$P = \gamma h \dots (2-4)$$

Where,

P = Hydrostatic pressure

ρ = Mass density of fluid in kilograms per cubic meter (metric) or slugs per cubic foot (British)

g = Acceleration of gravity

γ = Weight density of fluid in newtons per cubic meter (metric) or pounds per cubic foot (British)

h = Height of vertical fluid column above point of pressure measurement.

Differential pressure transmitters are the most common pressure-sensing device used in this capacity to infer liquid level within a vessel.

In the hypothetical case of the oil vessel just considered, the transmitter

would connect to the vessel in this manner (with the high side toward the process

And the low side vented to atmosphere):

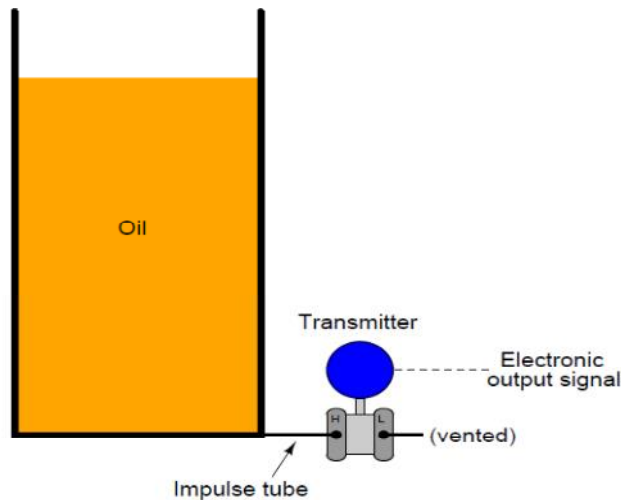


Figure 4.12 Hydrostatic pressure level measurements with Differential pressure transmitters

Connected as such, the differential pressure transmitter functions as a gauge pressure transmitter, responding to hydrostatic pressure exceeding ambient (atmospheric) pressure. As liquid level increases, the hydrostatic pressure applied to the “high” side of the differential pressure transmitter also increases, driving the transmitter’s output signal higher.

4.5 Bubbler systems:

An interesting variation on this theme of direct hydrostatic pressure measurement is the use of a purge gas to measure hydrostatic pressure in a liquid-containing vessel. This eliminates the need for direct contact

of the process liquid against the pressure-sensing element, which can be advantageous if the process liquid is corrosive.

This is how industrial “bubbler” level measurement systems work: a purge gas is slowly introduced into a “dip tube” submerged in the process liquid, so that no more than a few bubbles per second of gas emerge from the tube’s end. Gas pressure inside all points of the tubing system will (very nearly) equal the hydrostatic pressure of the liquid at the tube’s submerged end. Any pressure-measuring device tapped anywhere along the length of this tubing system will sense this pressure and be able to infer the depth of the liquid in the process vessel without having to directly contact the process liquid.

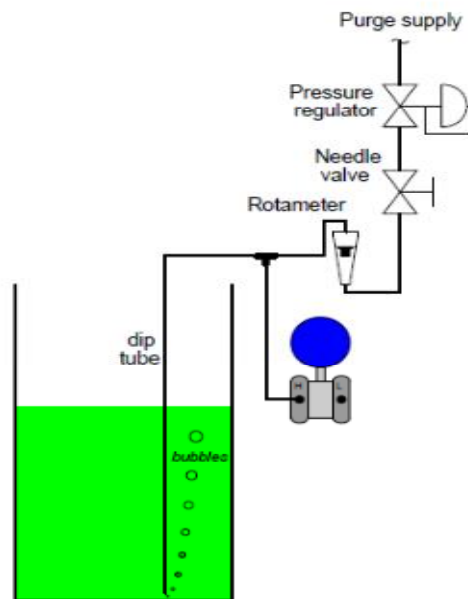


Figure 4.13 Bubbler system level measurements

4.6 Displacement:

Displacer level instruments exploit Archimedes' Principle to detect liquid level by continuously measuring the weight of an object (called the displacer) immersed in the process liquid. As liquid level increases, the displacer experiences a greater buoyant force, making it appear lighter to the sensing instrument, which interprets the loss of weight as an increase in level and transmits a proportional output signal.

Calculation of this buoyant force is a simple matter. According to Archimedes' Principle, buoyant force is always equal to the weight of the fluid volume displaced

$$F_{\text{buoyant}} = \gamma * V$$

Where

V the volume of the displacer

γ the weight density of the fluid

4.6.1 Buoyant-force instruments:

In practice a displacer level instrument usually takes the following form. Process piping in and out of the vessel has been omitted for simplicity – only the vessel and its displacer level instrument are shown:

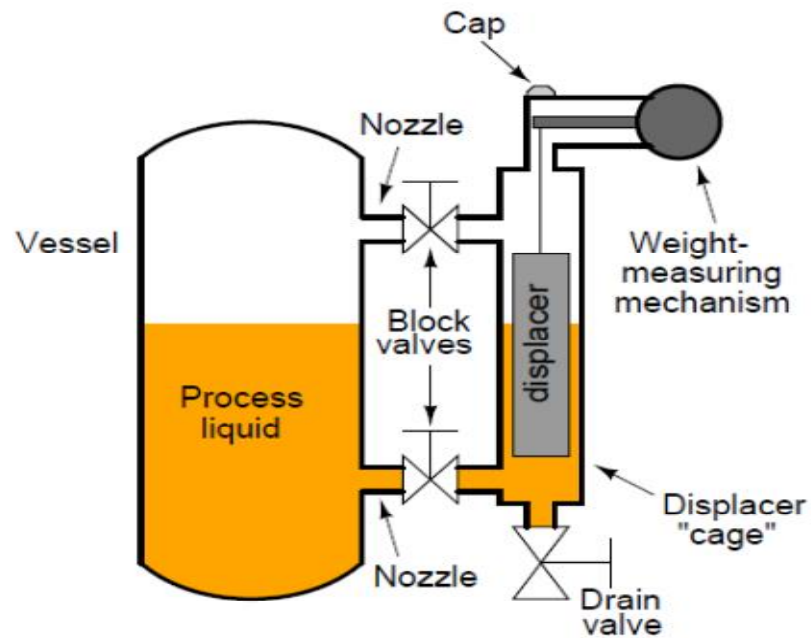


Figure 4.14 **Buoyant-force instruments**

The displacer itself is usually a sealed metal tube, weighted sufficiently so it cannot float in the process liquid. It hangs within a pipe called a “cage” which is connected to the process vessel through two block valves and nozzles. These two pipe connections ensure the liquid level inside the cage matches the liquid level inside the process vessel, much like a sight glass.

If liquid level inside the process vessel rises, the liquid level inside the cage rises to match. This will submerge more of the displacer’s volume, causing a buoyant force to be exerted upward on the displacer.

4.0.2 Displacement interface level measurement:

Displacer level instruments may be used to measure liquid-liquid interfaces just the same as hydrostatic pressure instruments. One important requirement is that the displacer always be fully submerged (“flooded”). If this rule is violated, the instrument will not be able to “tell” the difference between a low (total) liquid level and a low interface level.

If the displacer instrument has its own “cage,” it is important that both pipes connecting the cage to the process vessel (sometimes called “nozzles”) be submerged. This ensures the liquid interface inside the cage matches the interface inside the vessel. If the upper nozzle ever goes dry, the same problem can happen with a caged displacer instrument as with a “sight glass” level gauge

Calculating buoyant force on a displacer element due to a combination of two liquids is not as difficult as it may sound, according to Archimedes’ Principle: that buoyant force is equal to the weight of the fluid(s) displaced.

$$F_{\text{buoyant}} = \gamma_1 V_1 + \gamma_2 V_2$$

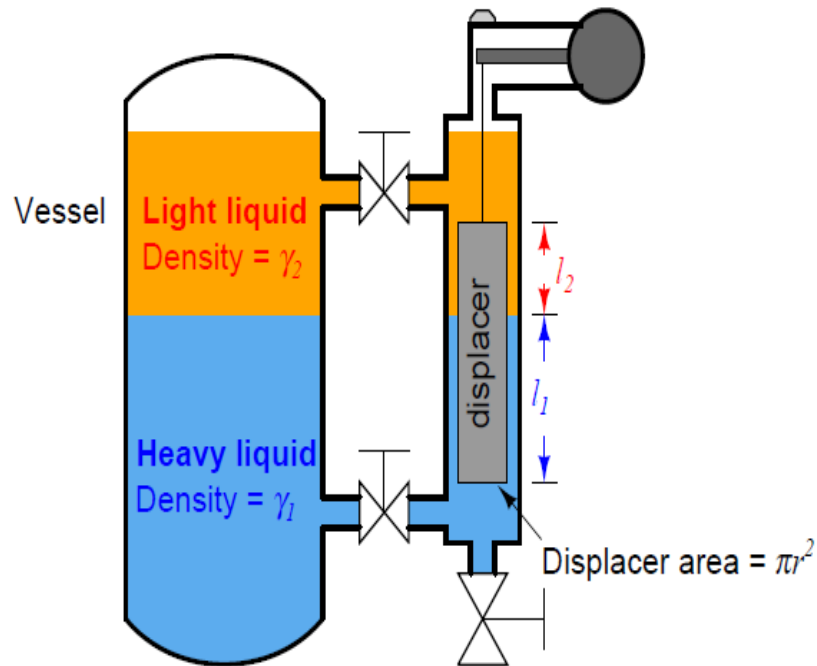


Figure 4.15 Displacement interface level measurement

4.7 Echo

A completely different way of measuring liquid level is to bounce a traveling wave off the surface of the liquid – typically from a location at the top of the vessel – using the time-of-flight for the waves as an indicator of distance, and therefore an indicator of liquid height inside the vessel. Echo-based level instruments enjoy the distinct advantage of immunity to changes in liquid density, a factor crucial to the accurate calibration of hydrostatic and displacement level instruments.

Liquid-liquid interfaces may also be measured with some types of echo-based level instruments, most commonly guided-wave radar.

The most important factor to the accuracy of an echo-based level instrument is the speed at which the wave travels en route to the liquid surface and back. So long as this velocity is known and stable, good level measurement accuracy is possible.

For ultrasonic (sound) echo instruments, the speed of sound is a strong function of medium density. Thus, an ultrasonic level transmitter measuring time-of-flight through a vapor above the liquid may drift out of calibration if the density in that vapor changes substantially, which may happen if the vapor's temperature or pressure happens to change.

Echo-based level instruments may be "fooled" by layers of foam resting on top of the liquid, and the liquid-to-liquid interface detection models may have difficulty detecting non-distinct interfaces, although this problem may be mitigated by installing guide tubes for the waves to travel in, or using wave probes as in the cases of guided-wave radar instruments. Liquid streams pouring in to the vessel through the vapor space may similarly cause problems for an echo instrument. Additionally, all echo-based instruments have dead zones where liquid level is too close to the transceiver to be accurately measured or even detected (the echo time-of-flight being too short for the receiving electronics to distinguish from the incident pulse).

4.8 Ultrasonic level measurement:

Ultrasonic level instruments measure the distance from the transmitter (located at some high point) to the surface of a process material located farther below using reflected sound waves. The time-of-flight for a sound pulse indicates this distance, and is interpreted by the transmitter electronics as process level. These transmitters may output a signal corresponding either to the fullness of the vessel (fillage) or the amount of empty space remaining at the top of a vessel (ullage).

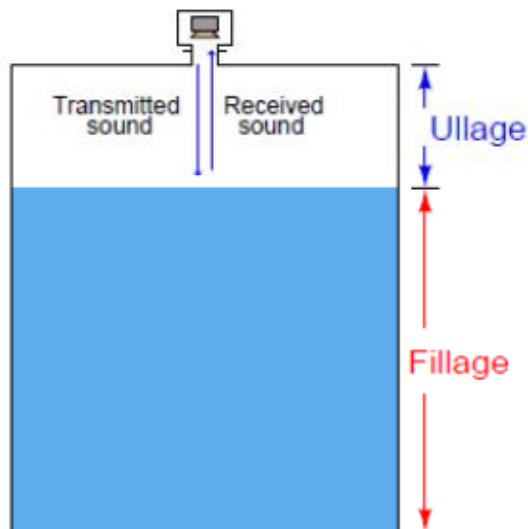


Figure 4.16 Ultrasonic level measurements

Ullage is the “natural” mode of measurement for this sort of level instrument, because the sound wave’s time-of-flight is a direct function of how much empty space exists between the liquid surface and the top of the vessel. Total tank height will always be the sum of fillage and

ullage, though. If the ultrasonic level transmitter is programmed with the vessel's total height, it may calculate fillage via simple subtraction:

$$\text{Fillage} = \text{Total height} - \text{Ullage}$$

4.9 Radar level measurement:

Radar level instruments measure the distance from the transmitter (located at some high point) to the surface of a process material located farther below in much the same way as ultrasonic transmitters – by measuring the time-of-flight of a traveling wave. The fundamental difference between a radar instrument and an ultrasonic instrument is the type of wave used: radio waves instead of sound waves.

Some radar level instruments use waveguide “probes” to guide the electromagnetic waves into the process liquid while others send electromagnetic waves out through open space to reflect off the process material. The instruments using waveguides are called guided-wave radar instruments, whereas the radar instruments relying on open space for signal propagation are called non-contact radar. The differences between these two varieties of radar instruments are shown in the following illustration:

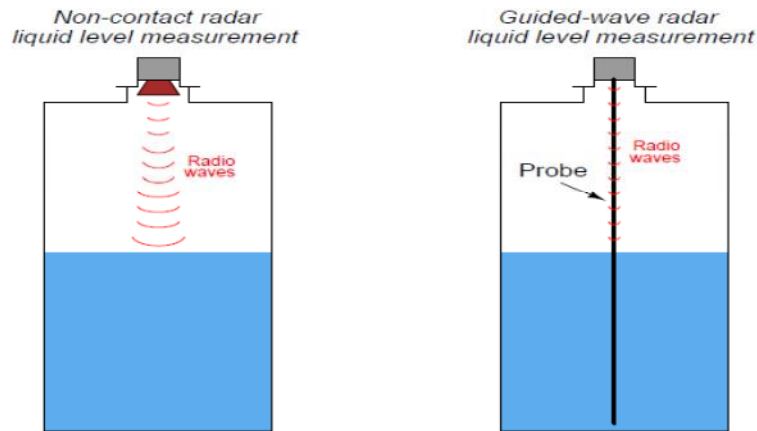


Figure 4.17 Radar level measurements

Probes used in guided-wave radar instruments do the best job guiding the microwave energy to the liquid interface and back. However, single-rod probes are much more tolerant of process fouling than two-rod or (especially) coaxial probes, where sticky masses of viscous liquid and/or solid matter cling to the probe. Such fouling deposits, if severe enough, will cause electromagnetic wave reflections that “look” to the transmitter like the reflection from an actual liquid level or interface.

Non-contact radar instruments rely on antennas to direct microwave energy into the vessel, and to receive the echo (return) energy. These antennas must be kept clean and dry, which may be a problem if the liquid being measured emits condensable vapors. For this reason, non-contact radar instruments are often separated from the vessel interior by means of a dielectric window (made of some substance that is relatively “transparent” to electromagnetic waves yet acts as an effective vapor barrier).

For liquid-liquid interfaces should be detectable using radar, and indeed they are. All that is needed is a sufficiently large difference in permittivity between the two liquids to create a strong enough echo to reliably detect.

4.10 Laser level measurement

The least-common form of echo-based level measurement is laser, which uses pulses of laser light reflected off the surface of a liquid to detect the liquid level. Perhaps the most limiting factor with laser measurement is the necessity of having a sufficiently reflective surface for the laser light to “echo” off of. Many liquids are not reflective enough for this to be a practical measurement technique, and the presence of dust or thick vapors in the space between the laser and the liquid will disperse the light, weakening the light signal and making the level more difficult to detect.

However, lasers have been applied with great success in measuring distances between objects. Applications of this technology include motion control on large machines.

4.11 Weight based instruments:

Weight-based level instruments sense process level in a vessel by directly measuring the weight of the vessel. If the vessel’s empty weight (tare weight) is known, process weight becomes a simple calculation of total weight minus tare weight. Obviously, weight-based level sensors

can measure both liquid and solid materials, and they have the benefit of providing inherently linear mass storage measurement. Load cells (strain gauges bonded to a steel element of precisely known modulus) are typically the primary sensing element of choice for detecting vessel weight. As the vessel's weight changes, the load cells compress or relax on a microscopic scale, causing the strain gauges inside to change resistance. These small changes in electrical resistance become a direct indication of vessel weight.

The following photograph shows three bins used to store powdered milk, each one supported by pillars equipped with load cells near their bases:



Figure 4.18 Weight based instruments

A close-up photograph shows one of the load cell units in detail, near the base of a pillar:



Figure 4.19 load cell units

Weight-based measurements are often employed where the true mass of a quantity must be ascertained, rather than the level. So long as the material's density is a known constant, the relationship between weight and level for a vessel of constant cross-sectional area will be linear and predictable.

One very important caveat for weight-based level instruments is to isolate the vessel from any external mechanical stresses generated by pipes or machinery.

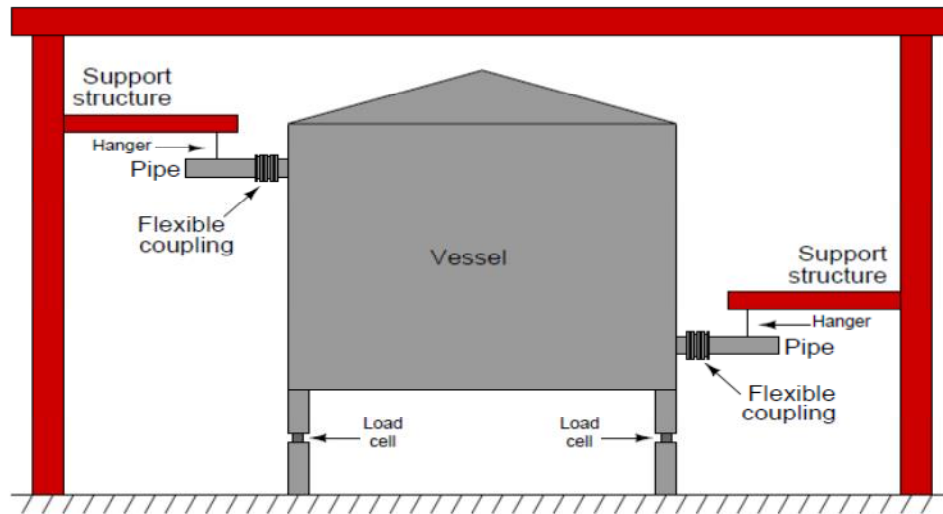


Figure 4.20 Weight-based measurements with isolate vessel

A similar concern for weight-based batch measurement is vibration produced by machinery surrounding (or on) the vessel. Vibration is nothing more than oscillatory acceleration, and the acceleration of any mass produces a reaction force ($F = ma$). Any vessel suspended by weight sensing elements such as load cells will induce oscillating forces on those load cells if shaken by vibration. This concern in particular makes it quite difficult to install and operate agitators or other rotating machinery on a weighed vessel

4.12 Capacitive level instruments

Capacitive level instruments measure electrical capacitance of a conductive rod inserted vertically into a process vessel. As process

level increases, capacitance increases between the rod and the vessel walls, causing the instrument to output a greater signal.

The basic principle behind capacitive level instruments is the capacitance equation:

$$C = \frac{\epsilon A}{d}$$

Where,

C = Capacitance

q = Permittivity of dielectric (insulating) material between plates

A = Overlapping area of plates

d = Distance separating plates

The amount of capacitance exhibited between a metal rod inserted into the vessel and the metal walls of that vessel will vary only with changes in permittivity (q), area (A), or distance (d). Since A is constant (the interior surface area of the vessel is fixed, as is the area of the rod once installed), only changes in q or d can affect the probe's capacitance.

Capacitive level probes come in two basic varieties: one for conductive liquids and one for nonconductive liquids. If the liquid in the vessel is conductive, it cannot be used as the dielectric (insulating) medium of a capacitor. Consequently, capacitive level probes designed for conductive liquids are coated with plastic or some other dielectric substance, so the metal probe forms one plate of the capacitor and the conductive liquid forms the other:

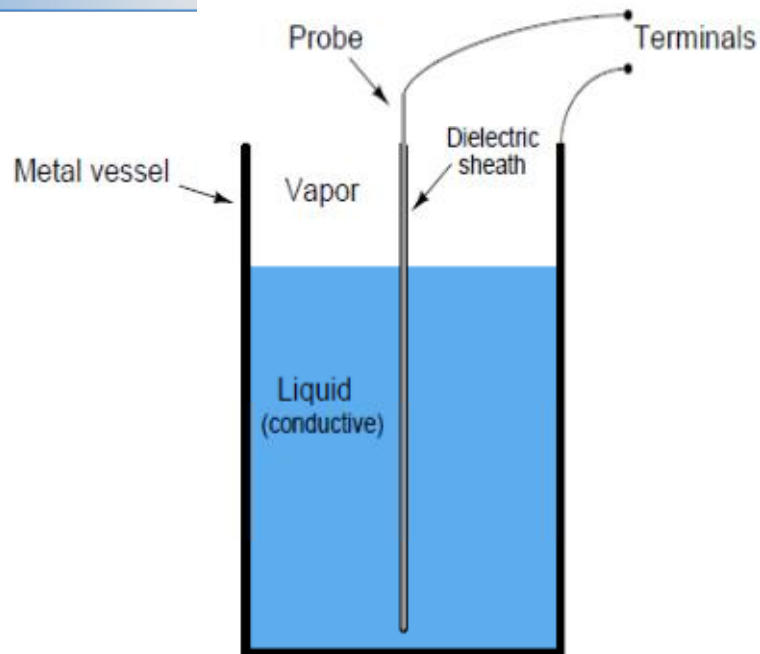


Figure 4.21 Capacitive level instruments

This means total capacitance will be greatest when the vessel is full (q is greatest and effective distance d is at a minimum), and least when the vessel is empty (q of the gas is in effect, and over a much greater distance).

If the liquid is non-conductive, it may be used as the dielectric itself, with the metal wall of the storage vessel forming the second capacitor plate. The probe is just a bare metal cable or rod:

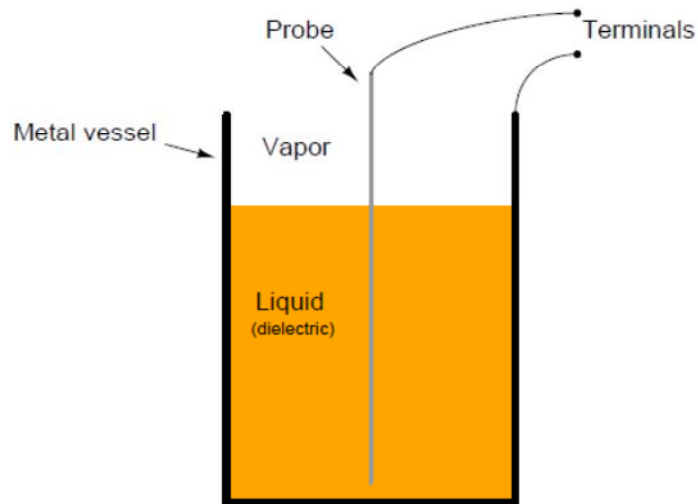


Figure 4.22 Capacitive level instruments with probe (rod)

In this style of capacitive level probe, the variable is permittivity (ϵ), provided the liquid has a substantially greater permittivity than the vapor space above the liquid. This means total capacitance will be greatest when the vessel is full (average permittivity ϵ is at a maximum), and least when the vessel is empty.

Capacitive level instruments may be used to measure the level of solids (powders and granules) in addition to liquids. In these applications, and solid substance is almost always non-conductive, and therefore the permittivity of the substance becomes a factor in measurement accuracy. This can be problematic, as moisture content variations in the solid may greatly affect permittivity, as can variations in granule size. They are not known for great accuracy, though, primarily due to

sensitivity to changes in process permittivity and errors caused by stray capacitance in probe cables.

4.13 Radiation

Certain types of nuclear radiation easily penetrates the walls of industrial vessels, but is attenuated by traveling through the bulk of material stored within those vessels. By placing a radioactive source on one side of the vessel and measuring the radiation making it through to the other side of the vessel, an approximate indication of level within that vessel may be obtained. Other types of radiation are scattered by process material in vessels, which means the level of process material may be sensed by sending radiation into the vessel through one wall and measuring back-scattered radiation returning through the same wall.

Nuclear radiation sources consist of radioactive samples contained in a shielded box. The sample itself is a small piece of radioactive substance encased in a double-wall stainless steel cladding, typically resembling a medicinal pill in size and shape. The specific type and quantity of radioactive source material depends on the nature and intensity of radiation required for the application. The basic rule here is that less is better: the smallest source capable of performing the measurement task is the best one for the application.

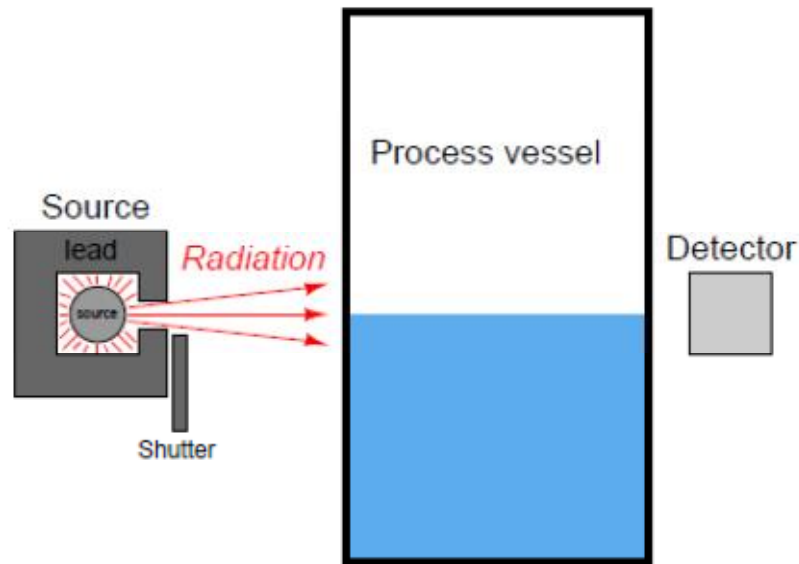


Figure 4.23 Radiation level measurements

4.14 Level sensor accessories

Disturbances in the liquid tend to complicate liquid level measurement. These disturbances may result from liquid introduced into a vessel above the liquid level (splashing into the liquid's surface), the rotation of agitator paddles, and/or turbulent flows from mixing pumps. Any source of turbulence for the liquid surface (or liquid-liquid interface) is especially problematic for echo-type level sensors, which only sense interfaces between vapors and liquids, or liquids and liquids.

If it is not possible to eliminate disturbances inside the process vessel, a relatively simple accessory one may add to the process vessel is a vertical length of pipe called a stilling well.



Figure 4.24 liquid level measurements with stilling well

Stilling wells may be used in conjunction with many types of level instruments: floats, displacers, ultrasonic, radar, and laser to name a few. If the process application necessitates liquid-liquid interface measurement, however, the stilling well must be properly installed to ensure the interface level inside the well match the interface levels in the rest of the vessel, the stilling well must be completely submerged so the interface levels will always match.

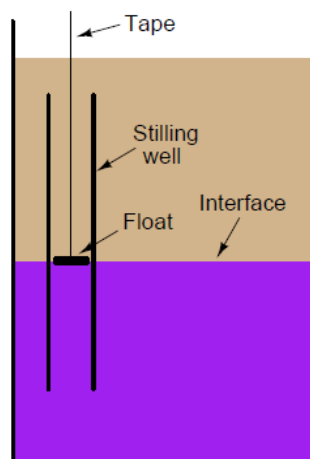


Figure 4.25 liquid level measurements with submerged stilling well

If it is not possible or practical to ensure complete submersion of the stilling well, an alternative technique is to drill holes or cut slots in the well to allow interface levels to equalize inside and outside of the well tube

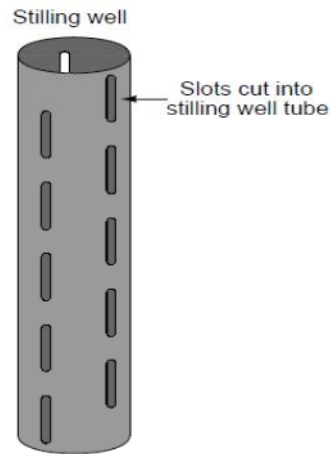


Figure 4.26 cut slots stilling well

Chapter Five: Water analytical Measurement

Most industrial production processes need cooling water for efficient and proper operation. Cooling water systems are an integral part of process operations in many industries. For continuous plant productivity, these systems require a specific chemical treatment. Monitoring water treatment systems are very important to determine effective and optimum treatment operation for the system with respect to energy, water, chemical usage and cost.

In the field of industrial instrumentation and process control, the word analyser generally refers to an instrument tasked with measuring the concentration of some substance. How do we measure the quantity of just one substance when thoroughly mixed with other substances?

Analytical instruments generally achieve selectivity by measuring some property of the substance of interest unique to that substance alone, or at least unique to it among the possible substances or at least unique to it among the possible substances. For example, a pH analyzer achieves hydrogen ion selectivity

By using a specially-prepared glass membrane intended to pass only hydrogen ions

5.1 Conductivity measurement

Electrical conductivity in metals is the result of free electrons drifting within a “lattice” of atomic nuclei comprising the metal object. When a

voltage is applied across two points of a metal object, these free electrons drift toward the positive pole (anode) and away from the negative pole (cathode).

Another case is electrical conductivity in liquids, the charge carriers are ions. Electrically imbalanced atoms that are free to drift because they are not “locked” into a lattice structure as is the case with solid substances. The degree of electrical conductivity of any liquid is therefore dependent on the ion density of the solution. When a voltage is applied across two points of a liquid solution, negative ions will drift toward the positive pole and positive ions will drift toward the negative pole. Finally Electrical conductivity in gases, ions is the charge carriers. However, with gases at room temperature, ionic activity is virtually nonexistent. A gas must be superheated into a plasma state before substantial ions exist which can support an electric current.

5.1.1 Dissociation and ionization in aqueous solutions:

Pure water is a very poor conductor of electricity. Some water molecules will “ionize” into unbalanced halves (instead of H_2O , there will be some negatively charged hydroxyl ions (OH^-) and some positively charged hydrogen ions (H^+), but the percentage is extremely small at room temperature. Any substance that enhances electrical conductivity when dissolved in water is called an electrolyte. This enhancement of conductivity occurs due to the molecules of the electrolyte separating into positive and

negative ions, which are then free to serve as electrical charge carriers. If the electrolyte is an ionically-bonded compound, the ions forming that compound separates in solution, this separation is called dissociation. If the electrolyte is a covalently-bonded compound, the separation of those molecules into positive and negative ions is called ionization.

Both dissociation and ionization refer to the separation of formerly joined atoms upon entering a solution. The difference between these terms is the type of substance that splits. Ionic impurities added to water immediately dissociate and become available to act as charge carriers. Thus, the measure of a water sample's electrical conductivity is a function of its ionic impurity concentration.

Conductivity is therefore an important analytical measurement for certain water purity applications, such as the treatment of boiler feed water, and the preparation of high-purity water used for semiconductor manufacturing. It should be noted that conductivity measurement is a very non-specific form of analytical measurement.

The conductivity of a liquid solution is a gross indication of its ionic content, but it tells us nothing specific about the type of ions present in the solution. Therefore, conductivity measurement is meaningful only when we have prior knowledge of the particular ionic species present in the solution

5.1.2 Two-electrode conductivity probes:

Conductivity is measured by an electric current passed through the solution. The most primitive form of conductivity sensor (sometimes referred to as a conductivity cell) consists of two metal electrodes inserted in the solution, connected to a circuit designed to measure conductance (G), the reciprocal of resistance ($1/R$):

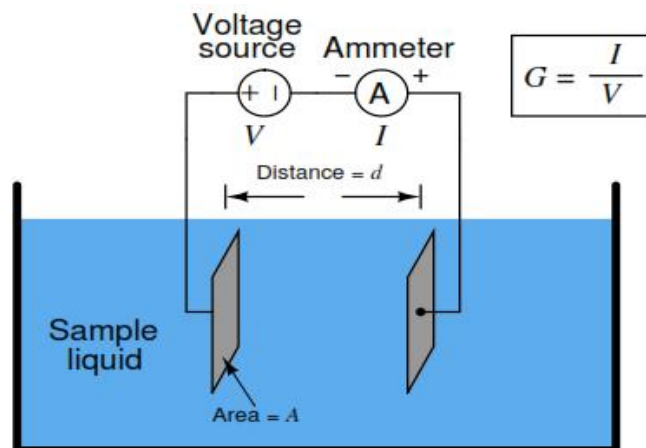


Figure 5.1 Two-electrode conductivity probes

5.1.3 Four-electrode conductivity probes

Is a very old electrical technique known as the Kelvin or four-wire resistance-measuring method. Commonly employed to make precise resistance measurements for scientific experiments in laboratory conditions, as well as measuring the electrical resistance of strain gauges and other resistive sensors, the four-wire technique uses four conductors to connect the resistance under test to the measuring instrument.

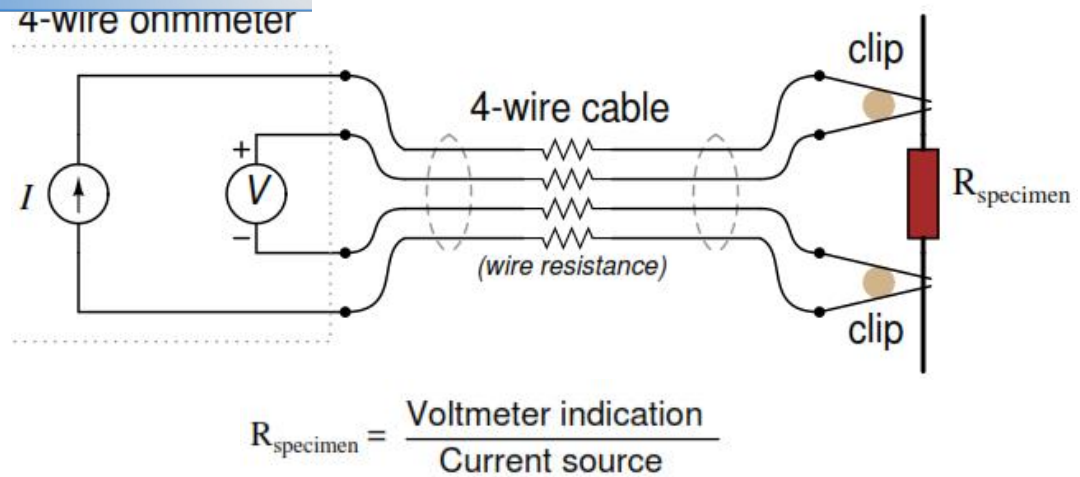


Figure 5.2 Four-electrode conductivity probes

Only the outer two conductors carry substantial current. The inner two conductors connecting the voltmeter to the test specimen carry negligible current (due to the voltmeter's extremely high input impedance) and therefore drop negligible voltage along their lengths.

Voltage dropped across the current-carrying (outer) wires is irrelevant, since that voltage drop is never detected by the voltmeter. Since the voltmeter only measures voltage dropped across the specimen (the resistor under test), and not the test resistance plus wiring resistance, the resulting resistance measurement is much more accurate.

5.1.4 Electrode less conductivity probes

A different design of conductivity cell called electrode less uses electromagnetic induction rather than direct electrical contact to detect the conductivity of the liquid solution.

This cell design enjoys the distinct advantage of virtual immunity to fouling, since there is no direct electrical contact between the measurement circuit and the liquid solution. This cell uses two toroidal inductors (one to induce an AC voltage in the liquid solution, and the other to measure the strength of the resulting current through the solution).

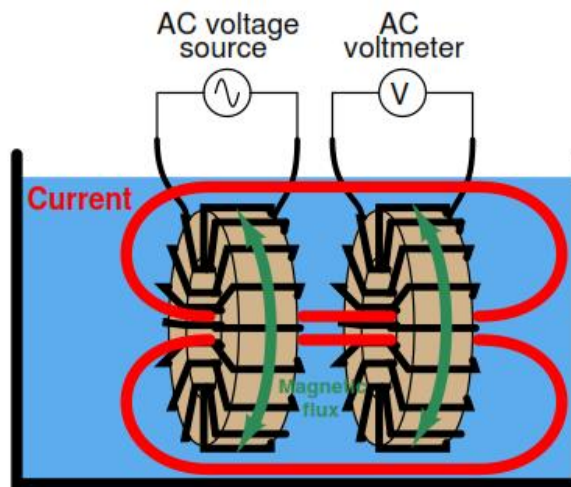


Figure 5.3 Electrode less conductivity probes

Since toroidal magnetic cores do an excellent job of containing their own magnetic fields, there will be negligible mutual inductance between the two wire coils. The only way a voltage will be induced in the secondary coil is if there is an AC current

passing through the center of that coil, through the liquid itself. The primary coil is ideally situated to induce such a current in the solution. The more conductive the liquid solution, the more current will pass through the center of both coils, thus producing a greater induced voltage at the secondary coil. Secondary coil voltage therefore is directly proportional to liquid conductivity.

5.2 pH measurement

PH is the measurement of the hydrogen ion activity in a liquid solution. It is one of the most common forms of analytical measurement in industry. pH has a great effect on the outcome of many chemical processes. Such as water treatment, pharmaceutical production, and steam generation (thermal power plants). pH is also a significant factor in the corrosion of metal pipes and vessels carrying aqueous (water-based) solutions.

5.2.1 Colorimetric pH measurement

One of the simplest ways to measure the pH of a solution is by color. Certain specific chemicals dissolved in an aqueous solution will change color if the pH value of that solution falls within a certain range. Litmus paper is a common laboratory application of this principle, where a color changing chemical substance infused on a paper strip changes color when dipped in the

solution. Comparing the final color of the litmus paper to a reference chart yields an approximate pH value for the solution.

5.2.2 Potentiometric pH measurement

Color-change is a common pH test method used for manual laboratory analyses, although it is not well suited to continuous process measurement. By far the most common pH measurement method in use is electrochemical: special pH-sensitive electrodes inserted into an aqueous solution will generate a voltage dependent upon the pH value of that solution. Like all other potentiometric (voltage-based) analytical measurements, electrochemical pH measurement is based on the Nernst equation, which describes the electrical potential by ions migrating through a permeable membrane. An of this is a device called a concentration cell, where two halves of an electrochemical cell are filled with solutions having different concentrations of ions (different molarities).

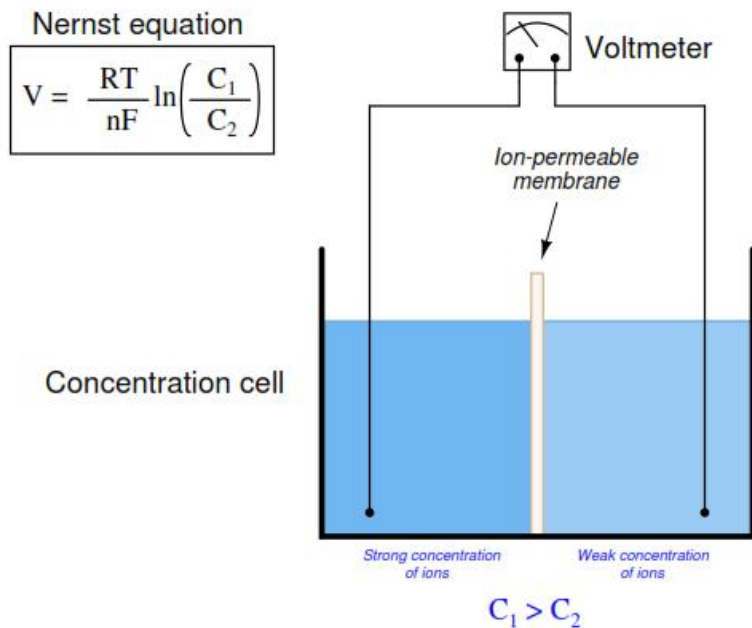


Figure 5.4 Potentiometric pH measurements

Where,

- V = Voltage produced across membrane due to ion exchange, volts (V)
- R = Universal gas constant (8.315 J/mol·K)
- T = Absolute temperature, in Kelvin (K)
- n = Number of electrons transferred per ion exchanged (unit less)
- F = Faraday constant, in coulombs per mole (96,485 C/mol e)

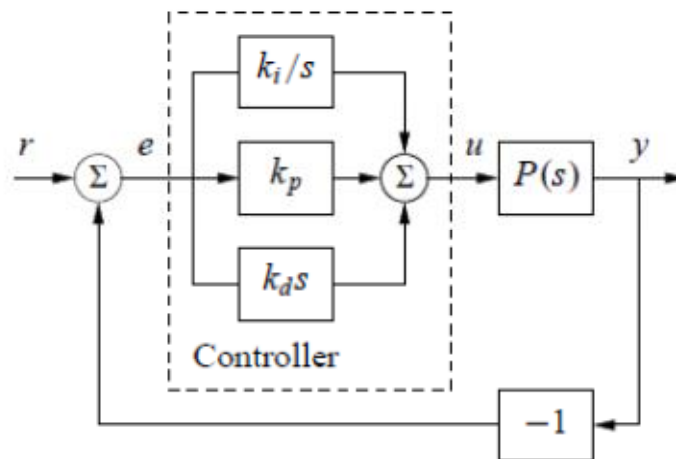
- C_1 = Concentration of ion in measured solution, in moles per liter of solution (M)
- C_2 = Concentration of ion in reference solution (on other side of membrane), in moles per liter of solution (M)

As ions naturally migrate through this membrane in an attempt to equalize the two concentrations, a voltage corresponding to the difference in ion concentrations between the two cell halves will develop between the two electrodes. The greater the difference in concentrations between the two sides, the greater the voltage produced by the cell. The Nernst voltage may be.

Chapter six: The level control PLC program

6.1 Theoretical review

In the level control system I will use the PID controller, PID control is by far the most common way of using feedback in engineering systems. It appears in simple devices and in large factories with thousands of controllers. PID controllers appear in many different forms: as stand-alone controllers, as part of hierarchical, distributed control systems and built into embedded components, Most PID controllers do not use derivative action, so they should strictly speaking be called PI controllers.



6.1 PID using error feedback

The control signal u for the system in Figure 6.1 is formed entirely from the error e , which is

$$\text{Error} = \text{set value} - \text{Measure value}$$

The command signal (r) is called the reference signal in regulation problems, or the set point in the literature of PID control. The Input / output relation for an ideal PID controller with error feedback is:

$$u = k_p e + k_i \int_0^t e(\tau) d\tau + k_d \frac{de}{dt} = k_p \left(e + \frac{1}{T_i} \int_0^t e(\tau) d\tau + T_d \frac{de}{dt} \right). \quad (6.1)$$

The control action is thus the sum of three terms: proportional feedback, the integral term and derivative action, the controller parameters are the proportional gain k_p , the integral gain k_i and the derivative gain k_d . The time constants T_i and T_d , called integral time (constant) and derivative time (constant), are sometimes used instead of the integral and derivative gains. The controller performs the PID mathematical functions on the error and applies the sum to a process, if tuned correctly; the signal measure value should move closer to set value.

Tuning a system means adjusting three multipliers K_p , K_i and K_d adding in various amounts of these functions to get the system to behave the way you want. We would like to obtain both of the following for the control system:

- 1- Fast responses, and
- 2- Good stability.

For level control it is possible to use PI (proportional plus integral) control. P or PI control can be used, although PI control is more common due to inaccuracies incurred due to offsets in P-only control, Derivative control is not considered due to the rapid fluctuations in flow dynamics with lots of noise.

The proportional term is used to give zero steady state error and the integral term allows the speed of closed loop response to be adjusted.

In today’s control engineering world, P-I-D is used over %95 of the control loops. Actually if there is control, there is P-I-D, in analog or digital forms. In order to achieve optimum solutions Kp, Ki and Kd gains are arranged according to the system characteristics. There are many tuning methods, but most common methods are as follows:

- 1- Manual Tuning Method
- 2- Ziegler-Nichols Method
- 3- Cohen-Coon Method
- 4- Internal Model Control
- 5- Auto Tune Variation

In this system I used manual tuning system; manual tuning is achieved by arranging the parameters according to the system response. Until the desired system response is obtained Ki, Kp and Kd are changed by observing system behavior.

For tuning the I use matlab program to observe the system response, to observe the rise time, overshoot, settling time and steady state error, firstly I get the transfer function from the process diagram:

$$Q_2 - Q_1 = Q \frac{A}{Q} \dots\dots\dots (6.2)$$

$$Q_1 = \frac{Q}{A} \dots\dots\dots (6.3)$$

A = area of basin
 Qi = inlet water flow rate

Q_0 —Outlet water flow rate

h = Height of water in basin

R = resistance

$$Q_0 - \frac{Q}{R} = Q \frac{dh}{dt} \dots\dots\dots (6.4)$$

$$Q_0 = \frac{Q}{R} + Q \frac{dh}{dt} \dots\dots\dots (6.5)$$

$$Q \frac{dh}{dt} = \frac{Q}{R} * Q (T) + Q \frac{dh}{dt} (T) \dots\dots\dots (6.6)$$

$$\frac{Q \frac{dh}{dt}}{Q (T)} = \frac{Q}{T \frac{dh}{dt} (T)} \dots\dots\dots (6.7)$$

$$T=RA$$

T is the delay time or lag response of the process

Assume that

$$R =1$$

For the control valve

$$T = 20 \text{ msec}$$

$$\frac{Q \frac{dh}{dt}}{Q (T)} = \frac{Q}{T \frac{dh}{dt} (T)} \dots\dots\dots (6.8)$$

For the measurement sensor

$$T= 2 \text{ msec}$$

$$\frac{Q \frac{dh}{dt}}{Q (T)} = \frac{Q}{T \frac{dh}{dt} (T)} \dots\dots\dots (6.9)$$

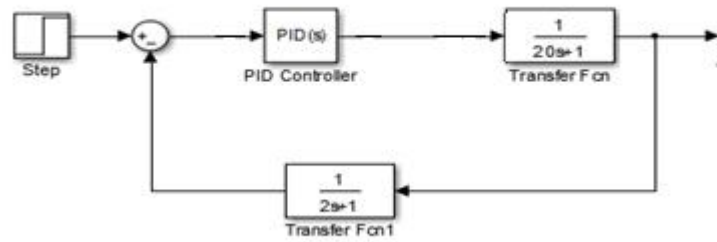
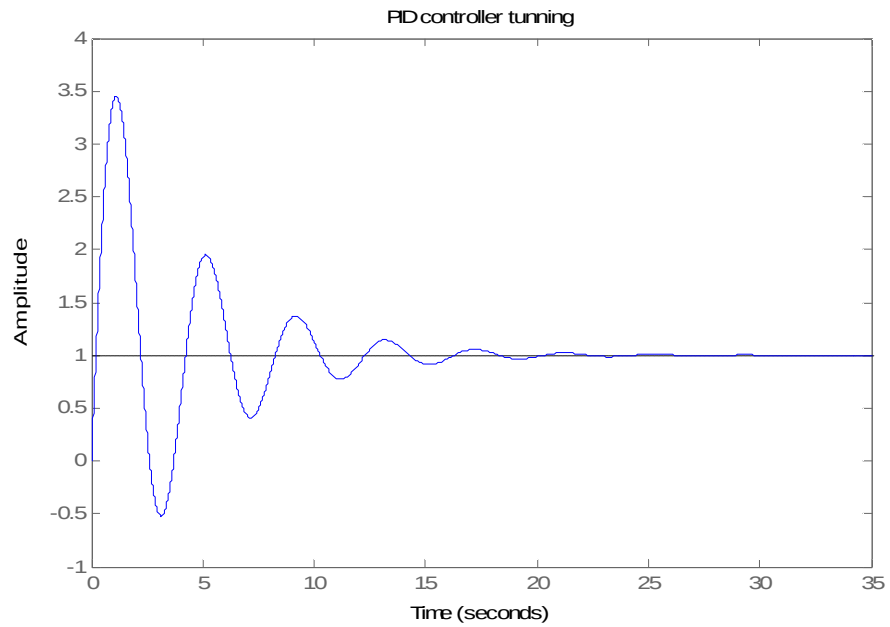
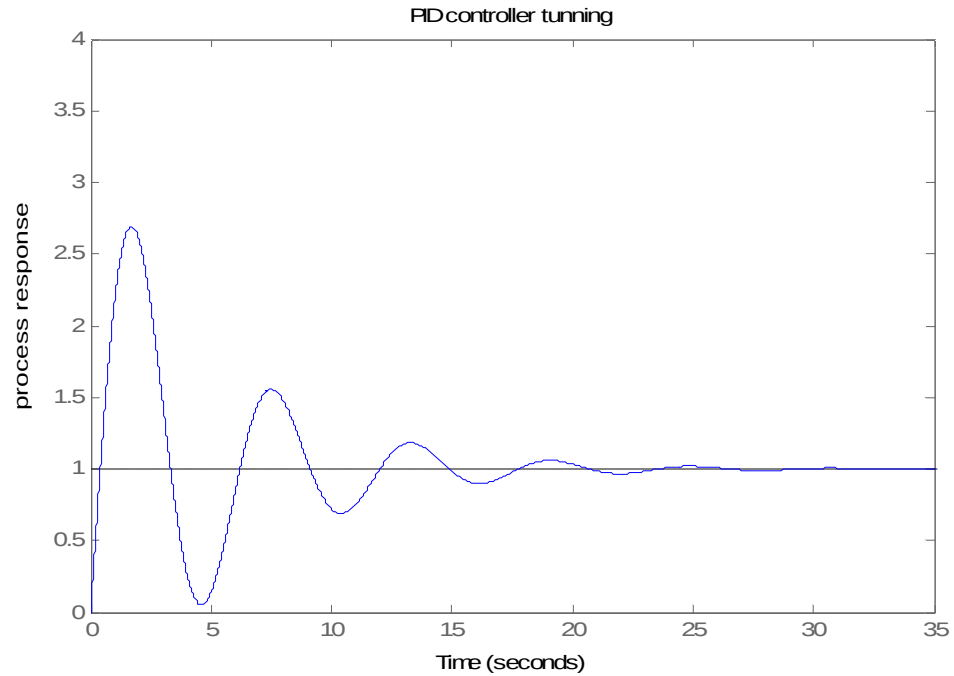


Figure 6.2 the matlab program

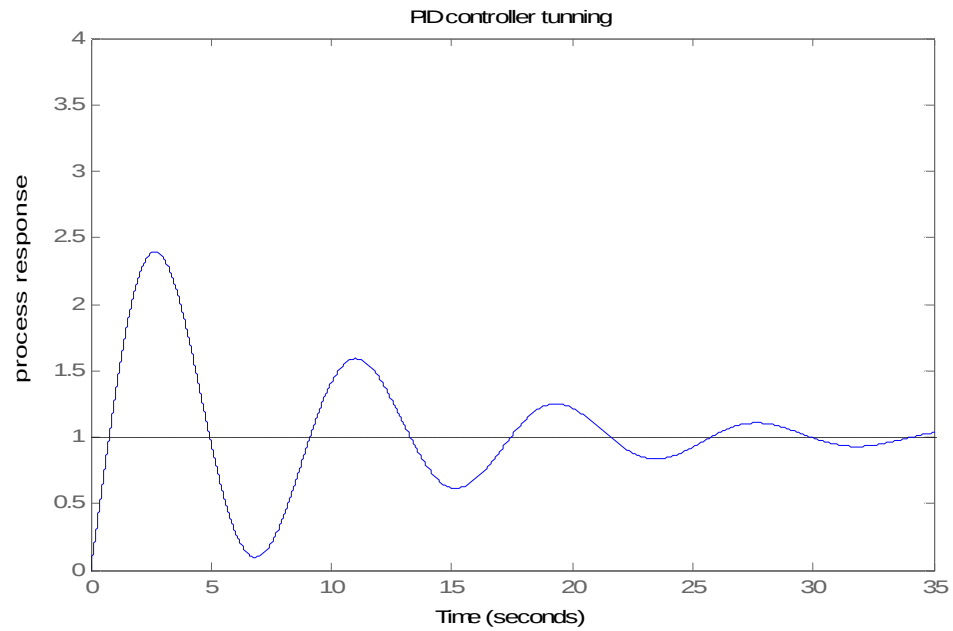
```
clc
kp=[100 50 25 25];
ki=[8 8 5 2];
c=PID(kp, ki)
s=tf('s');
p1=1/(20*s+1)
p2=1/(2*s+1)
T=feedback(c*p1, p2)
t=0:0.01:35;
Step(T, t)
Title('PID controller tuning')
```



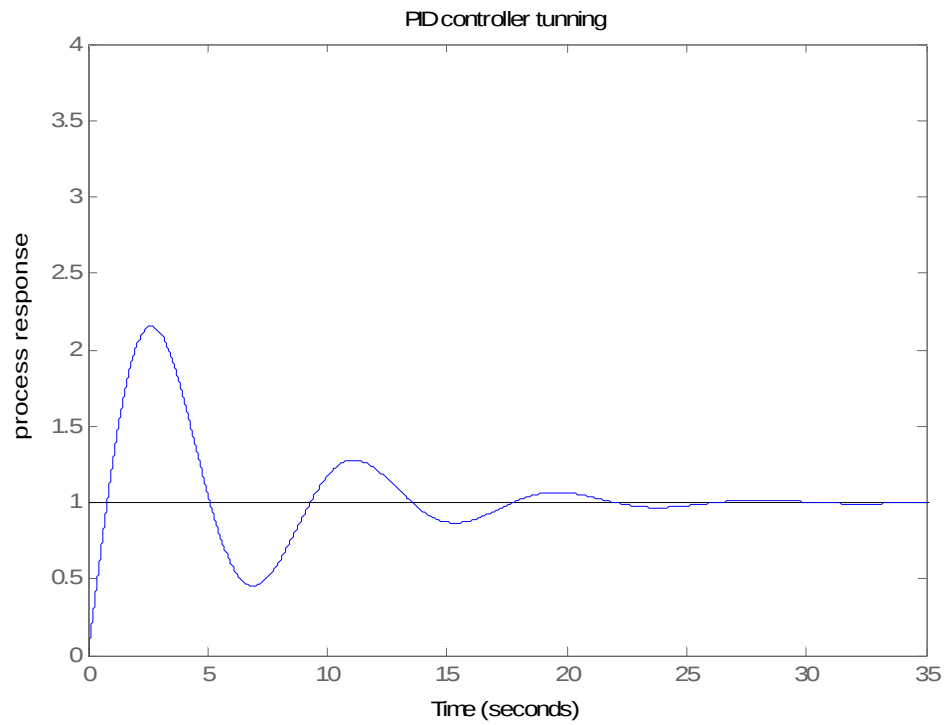
$K_p=100$, $K_i=8$



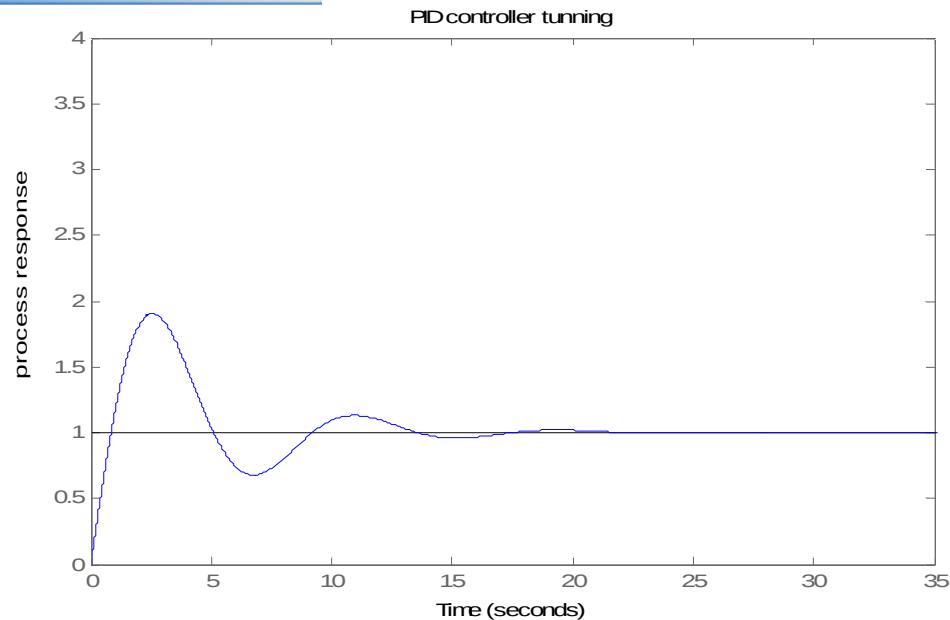
$K_p=50$, $K_i=8$



$K_p = 25$, $K_i = 8$



$K_p = 25$, $K_i = 5$



$$K_p = 25 \quad , \quad K_i = 2$$

The research main issue is the level control of the cooling tower basin, because of the old control system suffer from many disadvantages that in result damage many equipments and pipes that related to the operating system of the cooling tower, the old control system mainly depend on float level measurement to open and close the mechanical valve that feed the basin with makeup water from storage tanks through a pump.

In the start up of the generation unit The system description is as follow , at the first the control valve which known in the system as the makeup valve will open 100% and the pump of the storage tanks will operate to fulfill the basin of the cooling tower to the desired level - which is known as set point- and as the basin level going up the feedback signal from the level sensor will send to the controller which in turn send a signal to decrease the opening of the valve

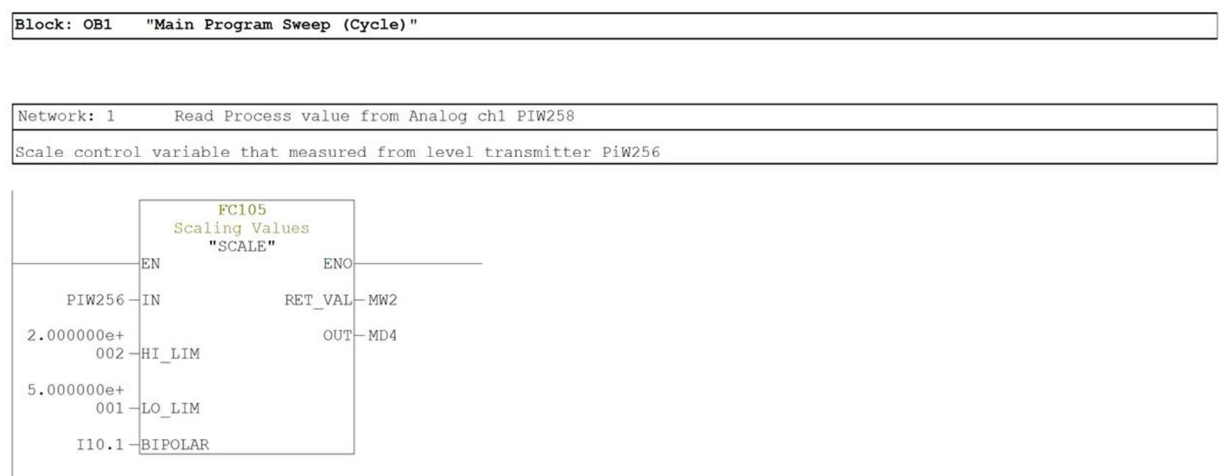
continuously till it fully closed when the level of basin reach the set point and the pump will stop , the cooling tower system will begin its normal operation by mean of the cooling water pump will drew the water from the basin and send it through the cooling system- AKA heat exchanger and condenser - and back again to the cooling tower through a pipe at the top of the cooling tower building , the water will drop down through the fill or nozzles which Spraying the water drops to a tiny drops to help in cooling the water by the fans in the top of the cooling tower which provide air that contact the water to cool it and evaporate some to the atmosphere , then to the basin and back again to the cooling system during this process the is amount of water lost so the level control system will compensate it.

While the water coming through to the basin there are many chemical additive must be add to it to protect the cooling system equipments from scaling and corrosion , this process called water treatment , by mean of the water in cooling tower basin must have certain chemical properties in certain range , which are the PH - **pH** is a measure of how acidic/basic water is – in our cooling tower the PH in the range (7.5 – 7.8) , and the conductivity of the water - **Conductivity** is a measure of water's capability to pass electrical flow - in our cooling tower the **Conductivity** must be equal to or less than 1500 μ s/cm ,in the cooling tower there are online meters to measure the PH and the conductivity in case it measures values that exceeds the limit there are drain valves called the purges in the basin of the cooling tower will automatically open to drain the water and the level control system will open the makeup valve to compensate the water and maintain the water level in the desired level. When the makeup valve opens the PH level may increase, in

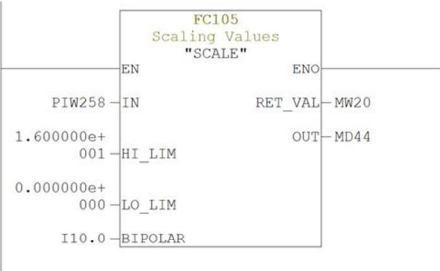
result the acid dosing system will operate to maintain the PH in the desired range, at the same time the conductivity is put under consideration to be maintained under $1500\mu\text{s}/\text{cm}$ at all times.

To control the level I use plc sematic s7-300 CPU 315-2PN/DP , with analog input analog output module to connected with the signal from ultrasonic level sensor to control makeup valve and pump on storage tank , for the online analytical measurements I used a PH sensor and Conductivity sensor , in the plc program for the control valve I used PID controller FB41- aka continuous control – the parameters of the controller is set by matlab program by try and error method till I reach to a good response theoretically. The main program is create it in OB1 which contain the scaling of all analog signals of the sensors , the start and stop of the storage tank pump, the operation of the drain valve and dosing acid pump in result of the analog signals send from sensors measurements

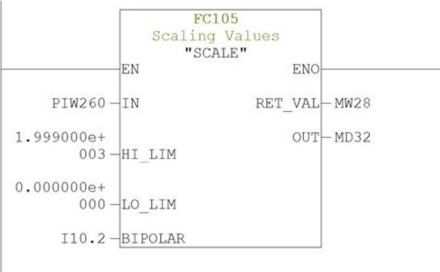
The fellow drawing is for the plc for the control valve:



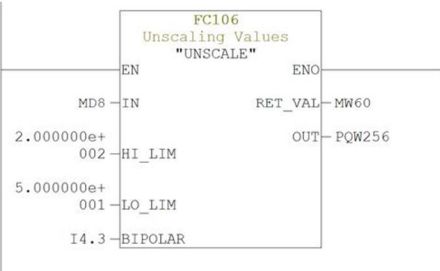
Network: 2
Scale control variable that measured from PH transmitter PIW258



Network: 3
Scale control variable that measured from conductivity transmitter PIW260



Network: 4
Scale control variable for control control valve PQW256





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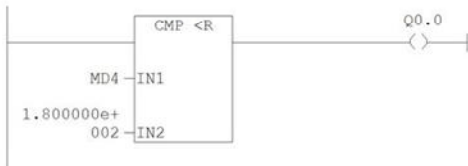
Network: 5

pump start and stop



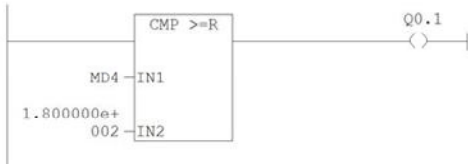
Network: 6

pump operation
pump on



Network: 7

pump operation
pump off



Network: 8

to open the drain valve when Ph is less than 7.5





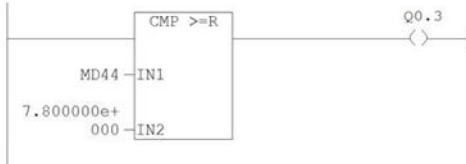
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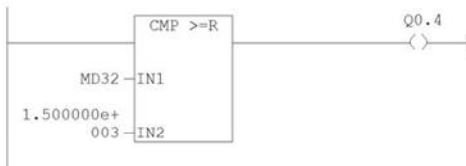
Network: 9

acid dosing pump start when ph is greater than 7.8



Network: 10

to open the drain valve when conductivity reach 1500



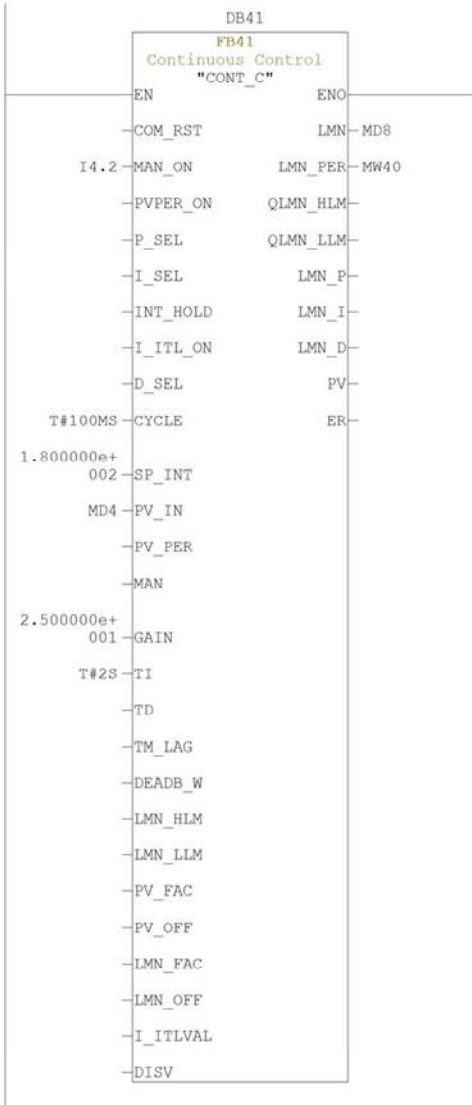


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Network: 1



Chapter Seven: Results and Discussions

The result for the program as follow:

For the main issue which is level measurement

The sensor reading PIW256 from 50 to 200

The PID desired value –aka set point - is 180

For control valve:

If the $50 < \text{PIW256} < 180$

Then the out of PID module will send signal to open the control valve.

If $\text{PIW256} > 180$

The out of PID module will send signal to close the control valve

For the pump:

If the $50 < \text{PIW256} < 180$

The out of comparator will send signal to set reset module to start the pump.

If $\text{PIW256} > 180$

The out of comparator will send signal to set reset module to stop the pump.

For the acid dosing pump:

If the $\text{PIW258} < 7.5$

The out of comparator will send signal to open the drain valve

If the $\text{PIW258} > 7.8$

The out of comparator will send signal to start the pump

For the conductivity measurement:



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If the I FW 200 > 1500

The out of comparator will send signal to open the drain valve.

Chapter Eight: Conclusion and recommendation:

For controlling and monitoring the cooling tower parameters I used PLC program, controlling the level by PID module and for tuning the PID parameters I used mat lab program, also there is a pump controlled by the level measurement to start and stop with the open and close of the control valve.

For the chemical additive I used for acid additive two comparators for start acid pump and open drain valve, for conductivity control one comparator to open the drain valve.

For further study on cooling tower controlling and monitoring, I recommend to control more parameters like cooling fans, and use microcontroller or any other computer program.



References

- 1- Modern power station practice volume E
- 2- Dr Mark J Willis , Control of level in process systems , Department of Chemical and Process Engineering University of Newcastle upon Tyne, October / November, 1999
- 3- Lessons In Industrial Instrumentation , By Tony R. Kuphaldt , Version 0.2 { Released September 29, 2008