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Sudan University of Science and Technology

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Design of an Automated Control System for Boilers Water Treatment Unit of Kenana Sugar Company

تصميم نظام تحكم آلي لوحدة معالجة مياه المراجل البخارية بشركة سكر كنانة

A Thesis Submitted as Partial Fulfillment of the Requirements
for the Degree of M.sc in Mechatronics Engineering

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الآية

قال الله تعالى ﴿ :لا يُكَلِّفُ اللَّهُ نَفْسًا إِلَّا وُسْعَهَا لَهَا مَا كَسَبَتْ وَعَلَيْهَا مَا اكْتَسَبَتْ رَبَّنَا لا تُؤَاخِذْنَا إِنْ نَسِينَا أَوْ أَخْطَأْنَا رَبَّنَا وَلا تَحْمِلْ عَلَيْنَا إِصْرًا كَمَا حَمَلْتَهُ عَلَى الَّذِينَ مِنْ قَبْلِنَا رَبَّنَا وَلا تُحَمِّلْنَا مَا لا طَاقَةَ لَنَا بِهِ وَاعْفُ عَنَّا وَاغْفِرْ لَنَا وَارْحَمْنَا أَنْتَ مَوْلانَا فَانصُرْنَا عَلَى الْقَوْمِ الْكَافِرِين ﴾ [البقرة:286].

Dedication

This thesis is lovingly dedicated to my respective parents who have been our constant source of inspiration. They have given us the drive and discipline to tackle any task with enthusiasm and determination.

Acknowledgement

First of all I would like to thank Allah, The Most Beneficent, The Most Merciful, for all His guidance and giving while I was preparing, doing and finishing this master thesis.

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Abstract

In the rapid development of flexible automation and the broad application of computer technology, industrial monitoring software has played an integral role in all kinds of industrial areas. It allows operators to monitor and control a plant in real-time with feedback from any number of processes.

The primary objective of this thesis is to develop an automatic control system for Kenana boilers water conditioning plant using Siemens simatic S7-300 Programmable Logic Controller (PLC) system in order to: ensure the optimum chemical dosing to avoid boilers tubes corrosion, reducing the operation cost by dosing the suitable amount of chemical according to PH & conductivity situations, to protect the boiler by supplying free water from sugar contaminants, and to assist in producing good quality steam.

The system has been designed and the control program has been written in ladder format, and checked by PLCSIM simulator software, the program include (Automatic blow down, Boiler PH control, and Automatic dumping system).

The communication between the plant and control system is built using Siemens WINCC SCADA , so the operators could achieved all control tasks through Human Machine Interface (HMI) screen pages.

المستخلص

في التطور السريع ل لأتمتة المرنة و التطبيق الواسع لتكنولوجيا الحاسوب لعبت برمجيات العرض الصناعية دورا كبيرا في جميع المجالات الصناعية. الأمر الذي يمكن المشغلين من مراقبة وضبط المحطة في الوقت الحقيقي مع وجود تغذية راجعة من أي عدد من العمليات.

الهدف الرئيسي من هذا البحث هو تصميم نظام تحكم آلي للتحكم فى وحدة معالجة مياه المراجل البخارية بمصنع سكر كنانة باستخدام المتحكمات المنطقية القابلة للبرمجة لشركة سيمنز (simatic S7-300 PLCs), وذلك من أجل : ضمان الجرعات الكيميائية الأمثل لتجنب تآكل أنابيب المراجل والحد من تكلفة التشغيل وذلك بضخ الكمية المناسبة من المواد الكيميائية وفقا لحالة المياه من حيث الأس الهيدروجيني (PH) و الموصلية الكهربية (conductivity)، حماية المراجل من خلال تزويدها بمياه نظيفة خالية من السكر، والمساعدة في إنتاج البخار بجودة عالية.

وقد تم تصميم النظام و كتابة برنامج التحكم بصورة المخطط السلمي (ladder diagram)، وتم اختباره باستخدام برنامج المحاكاة PLCSIM، و قد اشتمل برنامج التحكم على: التفريغ التلقائي للمرجل (automatic blowdown) ، و التحكم في الأس الهيدروجيني للغلايات (PH) ، و نظام العزل التلقائي للمياه المتكثفة في مبخرات عصير السكر في حالة تلوثها بجزيئات السكر قبل وصولها للمراجل (automatic dumping system).

تم بناء الاتصال بين المحطة و برنامج التحكم باستخدام (WINCC SCADA) لشركة سيمنز, لذا من السهل للمشغلين تنفيذ أفعال التحكم من خلال صفحات شاشة التحكم HMI.

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List of Abbreviations

AC	Alternating Current
AI	Analogue Input
AO	Analogue Output
BFWP	Boiler Feed Water pump
BFWT	Boiler Feed Water Tank
CMP	Compare
DC	Direct Current
DI	Digital Input
DO	Digital Output
FI	Flow Indicator
HMI	Human Machine Interface
I	Input
KSC	Kenana Sugar Company
LSP	Lower Setpoint
MB	Memory Bit
MS	Mild Steel
MV	Manipulated Variable
MW	Mega Watt
MW	Memory Word
NC	Normal Close
NO	Normal Open
O	Output
ODT	On Delay Timer
OFFDT	Off Delay Timer
PH	Power of Hydrogen
PI	pressure Indicator
PID	Proportional Integral Derivative
PLCs	Programmable Logic Controllers
PPM	Part Per Million
PS	Power Supply
PV	Process Variable
S7	Step 7
SCADA	Supervisory Control and Data Acquisition
SP	Set Point

T	Timer
TDS	Total Dissolved Solid
TI	Temperature Indicator
TOC	Total Organic Carbon
TPH	Ton Per Hour
TSV	Thermal Shutoff Valve
URV	Upper Range Value
USP	Upper Setpoint

CHAPTER ONE

INTRODUCTION

1.1 Background

Kenana boilers house consist of eight Takuma water tube boilers, six of them with steam production capacity of 113 T/H per boiler and the another two with capacity of 136 T/H each, the operating pressure and operating temperature are 31 kg/cm^2 and 370 ℃ respectively. There is special water treatment plant and a separate lab for boilers section.

Boiler is the most important part in thermal power stations; especially those are used in the sugar production factories as steam is used to generate electricity, drives cane sugar mills turbines …etc, in addition to its important role in the process of sugar production as steam is used in most sugar production stages such as evaporation of sugar juice. As the boilers are the heart of any sugarcane factory, boiler water treatment chemicals are an important part of the effective operation of the plant. Loss of steam production can mean a slowdown or virtual shutdown of mills. Because mills process a perishable commodity, this can cause loss of cane through deterioration or necessitate diversion of cane to another mill and loss of sugar juice at process side [1]. This can lead to higher final cost of product, so boiler side is critical aspect and need more concentration about.

1.2 Problem Statement

Considerable the water treatment plant of KSC boilers, the feed water of boilers is checked manually by taking samples with regular interval times, and depends only on human's efforts and there is no online monitoring and control of boiler water conditions such as PH and TDS of water which are considered an important parameters of boiler water, in other hand the return condensate of 1st effect evaporators is checked every 30 minutes so during this period the incidents of condensate sugar contamination may occur, the most important effect of these incidents was the severe loss of production and consequent financial losses ,in “Kenana” this incidents happened many times in several seasonal crops which caused significant and heavy leakage in boilers tubes and a long plant outage, due acidic corrosion of low feed water PH since sucrose breaks down at high temperature into organic acids, which lower the pH and this results in corrosion or excessive use of sodium hydroxide, and ultimately increases the total dissolved solids [2]. So this is an unusual situation for a modern power station.

1.3 Objectives

The main objective of this thesis is to design an automatic monitoring and control system for boiler water treatment plant of Kenana boiler using Siemens simatic s7-300 PLCs (programmable logic controllers), and simatic winc (SCADA); to achieve the following objectives:

1- Ensure the optimum chemical dosing to avoid corrosion by the way of:
    - Maintaining the correct alkalinity levels in the boiler by maintaining the correct PH.
    - Keeping metal surfaces clean and deposit free by controlling the level of TDS in the boiler.

2- Reducing the operation cost by dosing the suitable amount of chemical according to PH, conductivity and alkalinity situations.

3- To protect the boiler by supplying free water from sugar contaminants using automating dumping system during sugar contamination incidents to deliver the contaminated condensing water into wastage water tank.

4- Assist in producing good quality steam.

1.4 Methodology

The methodologies applied to achieve the objectives of this study are:

1- a brief descriptions of plant components and the effect of sugar contamination on condensate water has been discussed.

2- Site events investigation and assistance of experts.

3- The system has been evaluated and water sampling unit has been designed for online monitoring of the plant parameters such as PH, and conductivity, also the control system has been designed and Simatic S7-300 PLCs selected.

4- The control program has been written in ladder format, and checked by PLCSIM simulator.

5- Simatic WINCC HMI graphic pages has been created to inform the operator with all of the real-time information and to perform the operation actions.

1.5 Structure of the Thesis

This thesis consists of seven chapters. The scope of each chapter is explained as stated below:

Chapter one gives introduction to the research, including: background, problem statement, objectives, and methodology.

Chapter two gives general view of boiler water treatment unit components and related condensate systems, provides a discussion of boiler water treatment chemicals used in the plants, and gives brief description of the effect of sugar contamination on condensate water return to boiler from sugar juice evaporators.

Chapter three gives a brief description of operation principle of some online sensors, which are required to measure the conditions of boiler water and condensate water continuously.

Chapter four presents a description of the proposed control system which should be designed to automate the plant.

Chapter five introduces a detailed program of main control systems using simatic S7-300, also presents the SCADA system using Siemens wincc HMI software.

Chapter six draws general conclusion from the research and recommendations for future work.

CHAPTER TWO

PLANT OVERVIEW AND EFFECT OF SUGAR CONTAMINATION

2.1 Introduction

This chapter gives general view of boiler water treatment unit components and related condensate systems, provides a discussion of boiler water treatment chemicals used in the plants, and gives a brief description of the effects of sugar contamination on condensate water return to boiler from sugar juice evaporators. The whole view of the plant is shown in Figure 2.1 and a detailed description of each unit is discussed in the coming pages.

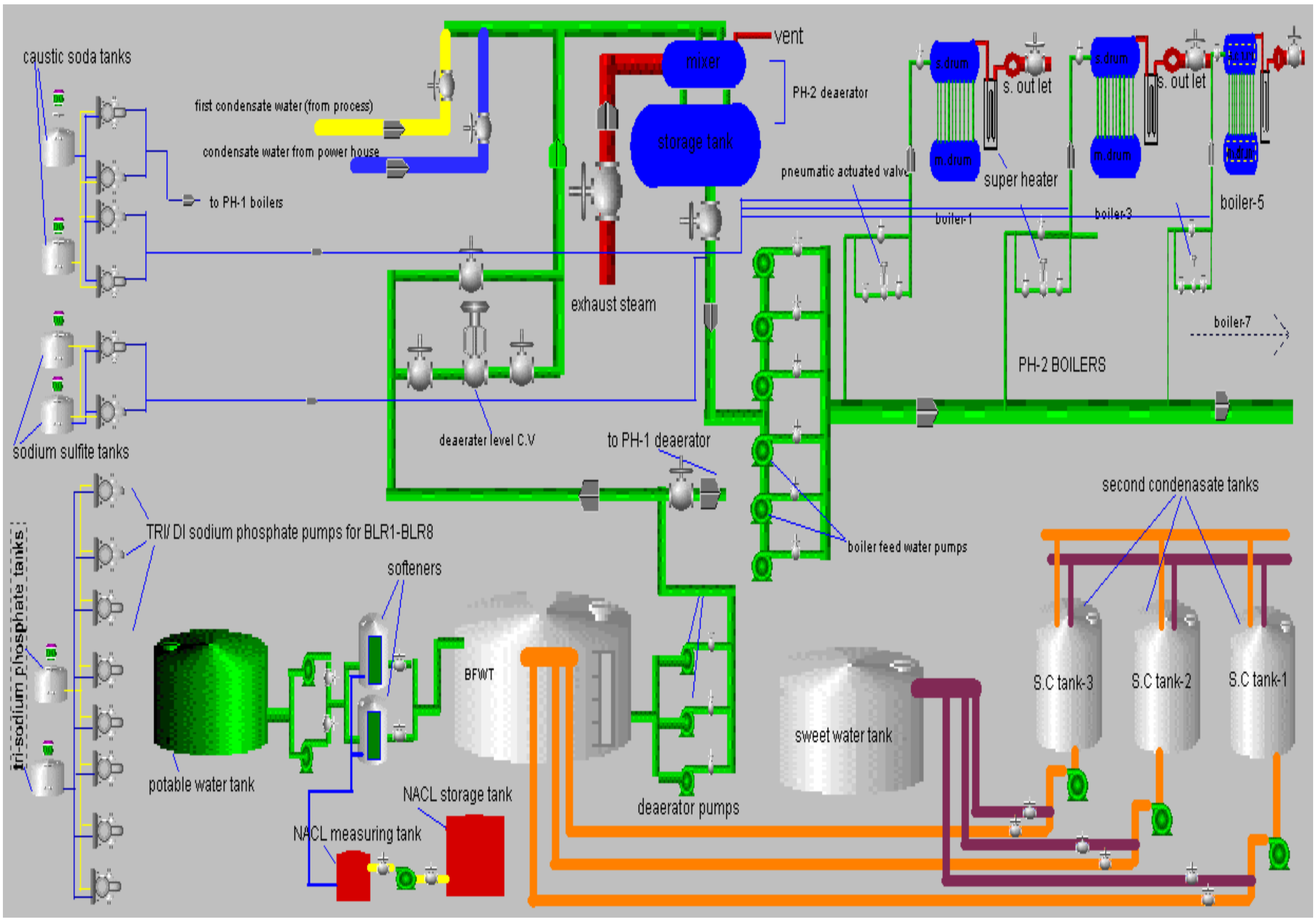


Figure2.1: Boiler plant view

2.2 Water Softening Plant

The first stage of treatment is to remove hardness salts (calcium and magnesium salts). Removal of hardness salts is called softening, this achieved by an ion-exchange process, and the hardness is removed as the water passes through bed of natural zeolite. The simplest type is ‘base exchange’ in which calcium and magnesium ions are exchanged for sodium ions. After saturation regeneration is done with sodium chloride. The sodium salts being soluble, do not form scales in boilers [4]. The water softening plant (see Figure 2.2) consists of:

2.2.1 Softener

Na vertical cylindrical type water softener and regeneration equipments, which are designed to supply water for the boilers.

- Type : Na type regeneration system
- Capacity : $68\ \mathrm{m}^3/\mathrm{hr} * 8.5\ \mathrm{hr} * 2\mathrm{units}$
- Regeneration time : Once 8.5 hr. about 1.5 hr.
- Raw water hardness : $100\ \mathrm{mg\ as\ Caco}_3$
- Regeneration chemicals: 100% NaCl
- Design pressure bar : $5.88\ \mathrm{kg/cm}^2$
- Size : 1500mm Ø x 1525mm ht.

Softener (figure2.2) were operated during off-crop to make-up boiler feed water tank and also operated during crop season for emergency if there is contamination of 1st condensate which leads to shortage of boiler feed water.

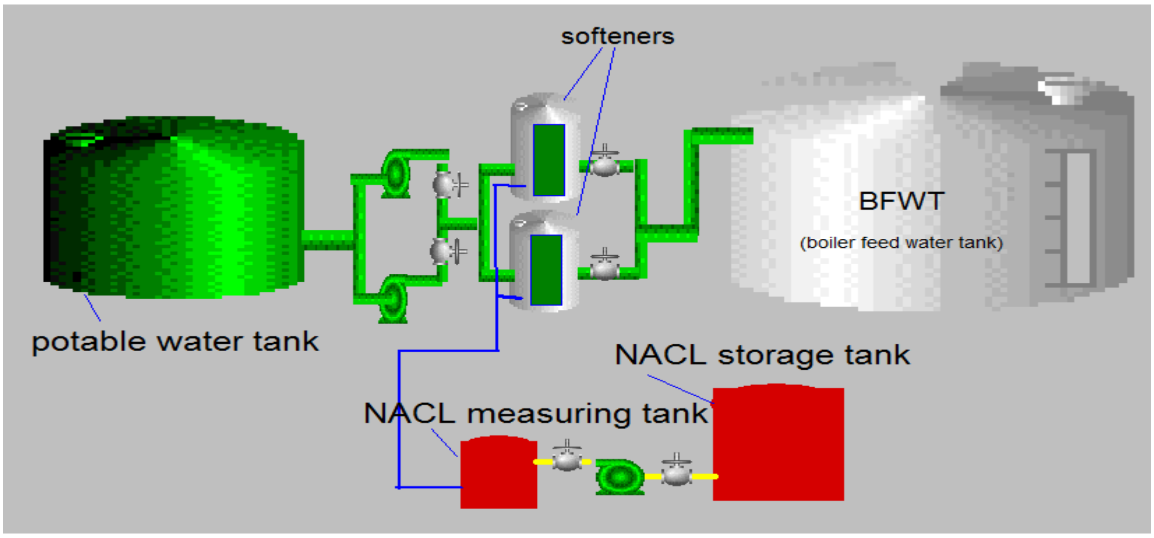


Figure 2.2: Water softening plant

2.2.2 Boiler feed water tank (BFWT)

This tank receives soften water and excess condensate (figure2.2).

- Type : M.S. plate made, vertical cylindrical type, Interior epoxy coating.
- Size : 23000 mm Ø × 9620 mm height, 4000 m^3 volume

2.2.3 Potable water tank

This tank receives raw water from main Kenana water treatment plant as storage for boiler needs (figure 2.2). Its water is useful for human uses but not suitable for boilers so it's pumped to softener plant to remove harness salts.

2.2.4 NaCl storage tank

This tank is used to prepare brine solution (NaCl) for softener regeneration (figure 2.2).

- Type : Mild steel plate made, vertical cylindrical type, interior epoxy coating.

- Size : 1900mm Ø × 2400mm height, 6800 lit volume.

2.2.5 Brine transfer pump (2 sets, 1 standby)

- Type :Volute pumps.
- Capacity: Flow rate 2.4 m^3/hr.
- Head : 5.4 meter.

These pumps are operated during off-crop to transfer brine solution to measuring tank (figure 2.2).

2.3 Chemical Dosing System

This system is used for internal treatment by dosing the suitable chemical according to boiler water condition to prevent the formation of scale by converting the scale-forming compounds to free-flowing sludge's which can be removed by blowdown, removing dissolve oxygen, and maintaining the PH of boiler water at normal level (PH=9.5 to 10 at steam drum). The system consist of eight reciprocating pumps for phosphate, four pumps for sulphite, and four for caustic soda as shown in the Figure 2.3.

2.3.1 The chemicals used in the plant

The following are chemicals used and their purposes:

2.3.1.1 Caustic soda:

To maintain a PH, it is dosed for each boiler at water feed line after drum level control valve as shown in figure 2.3.

2.3.1.2 Sodium sulphite:

To remove dissolved gases such asCO_2& O_2, this chemical is dosed at deaerator outlet line and before boiler feed water pumps.

2.3.1.3 Tri/ Di -sodium phosphate:

To control hardness and prevent the scale formation, this chemical is dosed directly to steam drum (upper drum).

2.3.2 Caustic soda preparation tank (2sets)

- Type : Stainless steel plate made, vertical cylindrical type.
- Size : 720mm Ø × 1000mm height, 0.36 m^3.

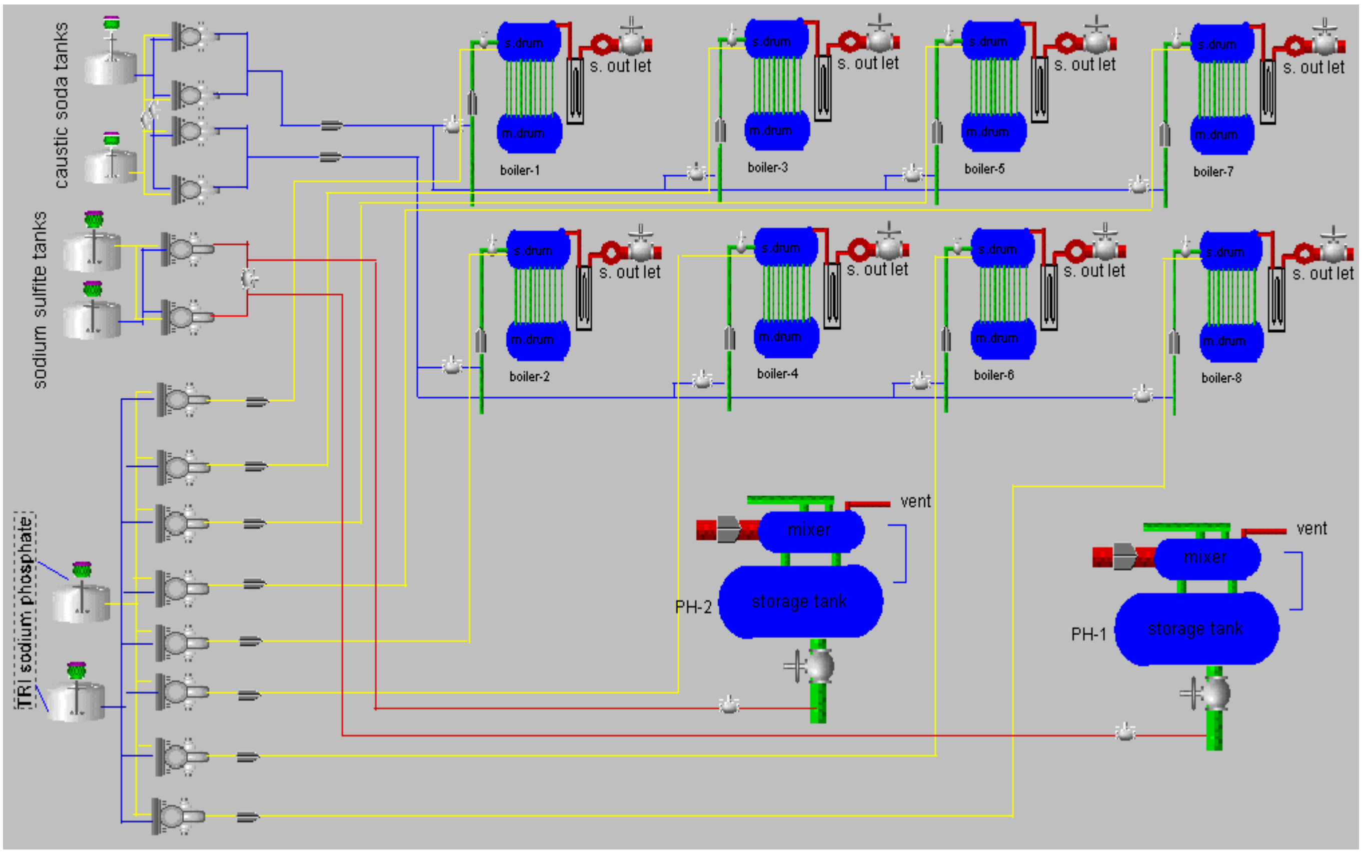


Figure2.3: Chemical dosing system

The following tanks are used for preparation of above mentioned chemicals:

These tanks are operated during crop season for caustic soda solution and during off-crop for disodium phosphate.

2.3.3 Sodium sulphite preparation tank (2 sets)

- Type: Stainless steel plate made, vertical cylindrical Type.
- Size: 635mm Ø × 700mm height, 0.2 m^3.

These tanks are operated during crop and off-crop.

2.3.4 Tri-sodium phosphate preparation tank (2sets).

- Type: Stainless steel plate made, vertical cylindrical type.
- Size : 880 mm Ø × 1000 mm height, 0.54 m^3.

2.4 The Deaerator

The deaerator removes dissolved gases by vigorously boiling the water and agitating it a process referred to as 'stripping'. The water entering at the top is mixed with steam which is rising upwards. The steam, taken directly from an exhaust steam of BFWP turbines, heats a stack of metal trays and as the water cascades down past these it mixes with the steam and becomes agitated, releasing the entrained gases. The steam pressurizes the deaerator and its contents so that the dissolved gases are vented to the atmosphere.

Minimizing corrosion requires the feed-water oxygen concentration to be maintained below 0.005 ppm or less and although the deaerator provides an effective method of removing the bulk of entrained gases it cannot reduce the concentration below about 0.005 ppm. For this reason, scavenging chemical (sodium sulphite) is added to remove the last traces of oxygen.

2.5 Condensate System

Steam is used in power house section for electrical power generation, in the power house there are six turbines with maximum capacity of 12 Mw each, and there are two types, one of them is called condensing turbine which required 5 TPH steam to produce 1 Mw, the exhaust steam (0.138 kg/cm^2) is passed through condenser and it’s condensate is pumped directly to deaerator, the other type is called back pressure turbine which required 9 TPH steam to produce 1 Mw, the exhaust steam (1.4 kg/cm^2) is coupled with exhaust steam from boiler and mill house turbines and used in sugar processing for concentration of sugar juice through heat exchangers (evaporators), which is condensed there and pumped to deaerator as 1st condensate [3].

The schematic diagram of the condensate system is illustrated in the following figure 2.4.

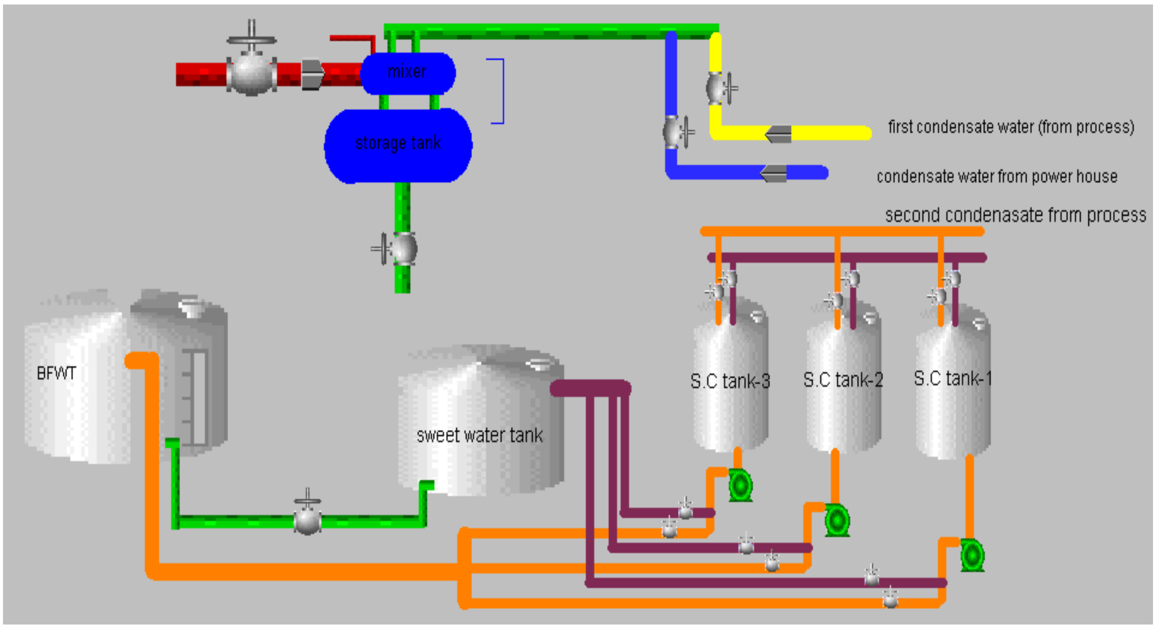


Figure 2.4: Condensate system

In multi effect evaporators (figure 2.5), the vapor of sugar juice at first effect evaporator is condensed in the next stage and called second condensate, this source of water is fed into second condensate receiving tanks to check for sugar contamination, if it is clean it will be pumped to boiler feed water tank otherwise it will be diverted to sweet water tank [3].

2.5.1 Sweet water tank:

- Type: M.S steel made, vertical cylindrical, interior epoxy coating.
- Size : 16200mm Ø × 9620mm height, 2000 m^3.

This tank operates during crop for 3rd and 4th condensate coming from bodies and 2nd contaminated condensate water. This tank sometime is used as boiler feed water tank when the boiler feed water tank is under maintenance.

2.5.2 2nd Condensate receiving tank (3set).

- Type: M.S steel made, vertical cylindrical, interior epoxy coating.
- Size : 4300mm Ø × 8220mm height, 120 m^3.

These tanks are used during crop season to receive 2nd condensate water from evaporators. If the water is good (after lab test) it is pumped to boiler feed water tank. If there is any contamination it is being pumped to sweet water tank [3].

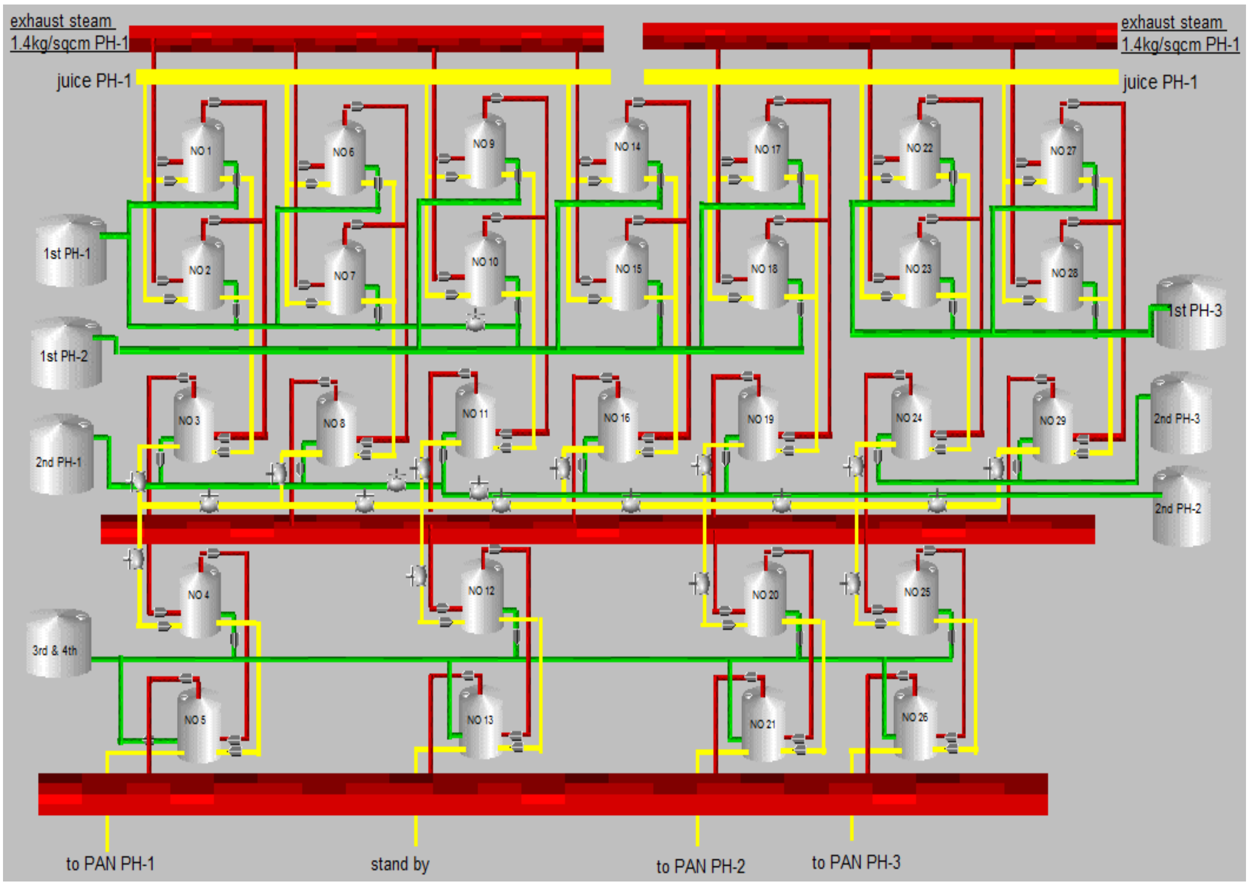


Figure 2.5: Multi effect evaporators

2.6 Effects of Sugar in Boilers

Condensate from the multiple effect evaporators used for concentrating sugar juice is frequently reclaimed and returned to the boiler. Evaporator condensate typically contains few contaminants this condensate is an ideal candidate for reuse as makeup water to the boiler. Occasionally, the condensate becomes contaminated with sugar from the process. Such "sugar shots" cause a depression in boiler water PH as the sugars break down into organic acids**;** this results in corrosion or excessive use of sodium hydroxide, and ultimately increases the total dissolved solids. At the high temperature the pH changes in relation to the sugar content of a solution, when heated to above 265°C. At a sucrose concentration of 50 ppm it was found that the PH could be expected to drop from 10.0 (which is the required level for boiler operation) by approximately 2.9 units [1].

If the presence of an excessive amount (i.e. > 200 ppm) of sugar in the boiler is not detected and dealt with, it can cause foaming, carry-over and fouling of strainers, steam traps, control valves, turbine blades ...etc; which can result in very expensive repairs. In addition the evaporation process causes carbonaceous deposits in the boiler drum and on heating surfaces of boiler tubes which reduce the heat transfer, and could cause corrosion and heavy leakage of boiler tube which may lead to complete shutdown of the plant to drain the contaminated water to repair the affected tubes. Sugar contamination is always a threat to any sugar factory that is recycling evaporator condensate to the boiler. Detection of the sugar shot is crucial and a prompt response imperative to minimize the potential for damage.

If the sugar shot is not detected soon enough; Boiler water PH can drop to 4PH in few minutes. Plant personnel often compensate by feeding large amounts of caustic to the system to increase the PH of the boiler water. This low PH drop simply re-dissolves the previous scale on the water-side internals. The feed of caustic in this situation provides time to buffer the acid and minimize the damage to the boilers. Carryover will still be a problem, but the boiler may now be more efficient, since the insulating deposit was removed. In case of boiler that is free of deposits, large amounts of iron will be dissolved into the boiler water as the direct result of metal corrosion. This can also occur if the low PH excursion lasts long after existing scale in a boiler has re-dissolved and the metal surface then comes in contact with the low PH water [1].

The feed of caustic will create significant problems in these situations. The iron hydroxide that is formed will redeposit back onto the boiler tubes, in the hottest heat transfer area. This deposit is very insulating and quite porous. Not only will heat transfer be lost, but the porosity of the deposit will allow caustic to seep behind the deposit, where it evaporates on the tube surface. Under-deposit corrosion will consequently occur and continue long after the sugar shot has been corrected.

Traces of sugar in boiler feed water up to some arbitrary level, possibly as high as 50 parts per million (ppm), are believed to be quite safe for the performance and safety of boilers, provided the chemical treatment of feed water is adequate. However the occasional heavy slugs of sugar which find their way into the feed water system can be very dangerous which need to be eliminated by an effective sugar monitoring system to protect the boilers [1].

2.7 The Incidents of Sugar Contamination

There have been many incidents of sugar contamination in Kenana boilers since the sugar industry is used steam. usually the incident starts with undetected entrainment or leakage of sugar into condensate at one or more bodies of multiple effect evaporators which eventually reveals itself by the characteristic smell of caramel emanating from steam drains. The pH in the boiler falls sharply and must be controlled by dosing caustic soda into the feedwater. If the pH responds to this control the boilers can be kept on line, provided an adequate supply of uncontaminated feed water [1].

The following is a brief list of some causes of these incidents in some sugar factories as well as Kenana:

- Failure of the juice level control in an evaporator caused juice to fill the vessel to the vapor outlet and flow through the condensate system into the second condensate tank.
- If the outlet of a juice line of any effect of the evaporator is blocked by any reason, example (missing of welding gloves or piece of cleaning cloth inside the line during maintenance period) which made it to fill up and overflow into the calandria of the next vessel and then inter to the boiler as second condensate .
- Several boiler shut downs have been caused by failure of juice heater tubes.
- Any leakages of evaporator or pan tubes, as sugar juice flow inside the tubes and heated by surrounding steam if for any reason the pressure of steam became less than juice pressure the juice will come out and mixed by steam; which caused sugar to reach the boilers.

These may be regarded as typical for the sugar industry, the most important effect of these incidents was the severe loss of production and consequent financial losses, but in no instance was there permanent damage to the boilers. In all of these incidents and in many others not recorded, the amount of sugar contamination was very high, and for different reasons was not detected by the laboratory people at instant time.

In all cases however the reasons are related to the type of monitoring system as in chemical sampling test the interval time between taking two samples is considered too long (about 30 minutes) so during this period sugar may entered the boilers. So, automatic dumping system is good solution of this problem which will be discussed in chapter four.

CHAPTER TREE

INSTRUMENTATION CONTINUOUS MEASURING DEVICES

3.1 Introduction

This chapter presented a brief description of operation principle of some important devices used as online sensors, which are required to measure the conditions of boiler water and condensate water (return from sugar evaporators section) continuously.

3 .2 Analyzers

In the field of industrial instrumentation and process control, the word analyzer generally refers to an instrument tasked with measuring the concentration of some substance, usually mixed with other substances of little or no interest to the controlled process. Unlike the other “bulk” measurement devices for sensing such general variables as pressure, level, temperature, or flow, an analytical device must discriminately select one material over all others present in the sample [5]. This single problem accounts for much of the complexity of analytical instrumentation: how do we measure the quantity of just one substance when thoroughly mixed with other substances?

3.2.1 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 immediately drift toward the positive pole (anode) and away from the negative pole (cathode).

Electrical conductivity in liquids is another matter entirely. Here, the charge carriers are ions: electrically imbalanced atoms or molecules 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 (how many ions freely exist per unit volume of liquid). When a voltage is applied across two points of a liquid solution, negative ions will drift toward the positive pole (anode) and positive ions will drift toward the negative pole (cathode). In honor of this directional drifting, negative ions are sometimes called anions (attracted to the anode), while positive ions are sometimes called cations (attracted to the cathode) [5].

3.2.2 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), you will find 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 in question is an ionically-bonded compound (table salt is a common example), the ions forming that compound naturally separate in solution, and this separation is called dissociation [5]. If the electrolyte in question is a covalently-bonded compound (hydrogen chloride is an example), 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: “dissociation” refers to the division of ionic compounds (such as table salt), while “ionization” refers to covalent-bonded (Molecular) compounds such as HCl which are not ionic in their pure state.

Ionic impurities added to water (such as salts and metals) immediately dissociate and become available to act as charge carriers. Thus, the measure of a water sample’s electrical conductivity is a fair estimate of ionic impurity concentration. Conductivity is therefore an important analytical measurement for certain water purity applications, such as the treatment of boiler feed water.

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 or types 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 (as in this research the purpose is to maintain the level of TDS in boiler water and to detect the contaminants in condensate system).

3.2.3 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$\frac{1}{R}$:

The schematic diagram of two-electrode conductivity cell is illustrated in the following figure 3.1.

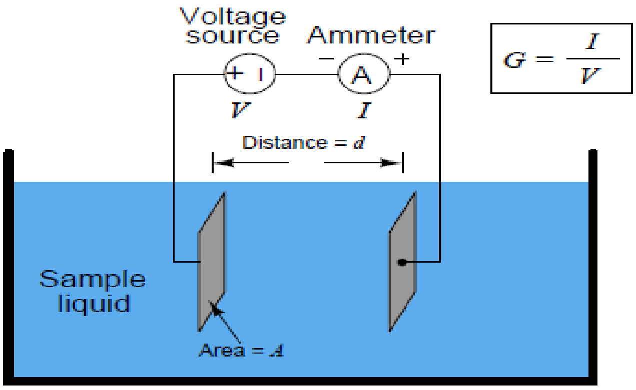


Figure 3.1Two-Electrode Conductivity Probes

The following photograph (figure 3.2) shows such direct-contact style of conductivity probe, consisting of stainless steel electrodes contacting the fluid flowing through a glass tube:

Figure 3.2 Direct-contact syle of conductivity probe

The conductance measured by a direct-contact conductivity instrument is a function of plate geometry (surface area and distance of separation) as well as the ionic activity of the solution. A simple increase in separation distance between the probe electrodes will result in a decreased conductance measurement (increased resistance R) even if the liquid solution's ionic properties not change. Therefore, conductance is not particularly useful as an expression of liquid conductivity. The mathematical relationship between conductance, plate area (A), plate distance (d), and the actual conductivity of the liquid (k) is expressed in the following equation:

$G= k\frac{A}{d}$…………………………………………………………..(3.1)

Where:

G : Conductance, in Siemens (S)

k : Specific conductivity of liquid, in Siemens per centimeter (S/cm)

A : Electrode area (each), in square centimeters (cm^2)

d : Electrode separation distance, in centimeters (cm)

For any particular conductivity cell, the geometry may be expressed as a ratio of separation distance to plate area, usually symbolized by the lower-case Greek letter theta (θ), and always expressed in the unit of inverse centimeters (cm^{-1}):

$\theta = \frac{d}{A}$……………………………………………………………(3.2)

Re-writing the conductance equation using θ instead of A and d, we see that conductance is the quotient of conductivity k and the cell constant θ:

$G = \frac{k}{\theta}$…………………………………………………………..(3.3)

Where:

θ : Cell constant, in inverse centimeters(cm^{-1})

Manipulating this equation to solve for conductivity given electrical conductance and, cell constant (θ), we have the following result:

$$k = G\theta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.4)$$

Two-electrode conductivity cells are not very practical in real applications, because mineral and metal ions attracted to the electrodes tend to “plate” the electrodes over time forming solid, insulating barriers on the electrodes. While this “electroplating” action may be substantially reduced by using AC instead of DC to excite the sensing circuit, it is usually not enough. Over time, the conductive barriers formed by ions bonded to the electrode surfaces will create calibration errors by making the instrument “think” the liquid is less conductive than it actually is.

3.2.4 Four-electrode conductivity probes

A very old electrical technique known as the Kelvin or four-wire resistance-measuring method is a practical solution for this problem. 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 as shown in figure 3.3.

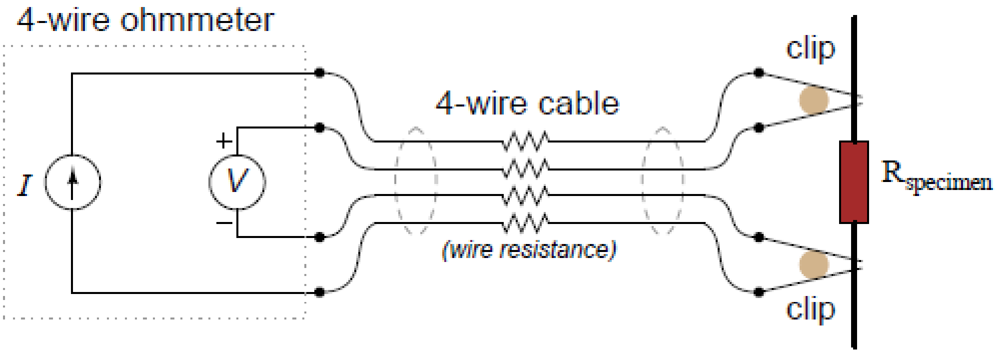


Figure 3.3 Kelvin or four-wire resistance-measuring method

$$\mathbf{R_{speciment}} = \frac{\text{Voltmeter indication}}{\text{Current source}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\mathbf{(3.5)}$$

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.

In the case of conductivity measurement, it is not wire resistance that we care to ignore, but rather the added resistance caused by plating of the electrodes. By using four electrodes instead of two (figure3.4), we are able to measure voltage dropped across a length of liquid solution only, and completely ignore the resistive effects of electrode plating:

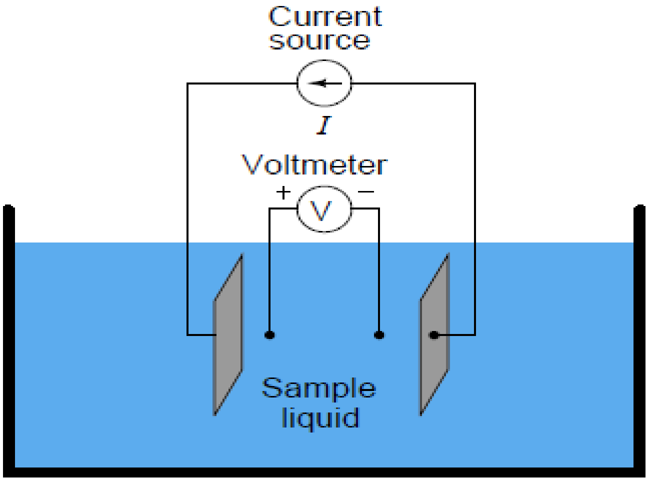


Figure 3.4 Four-electrode conductivity measurement

In the 4-wire conductivity cell, any electrode plating will merely burden the current source by causing it to output a greater voltage, but it will not affect the amount of voltage detected by the two inner electrodes as that electric current passes through the liquid. Some conductivity instruments employ a second voltmeter (figure3.5) to measure the voltage dropped between the "excitation" electrodes, to indicate electrode fouling [5].

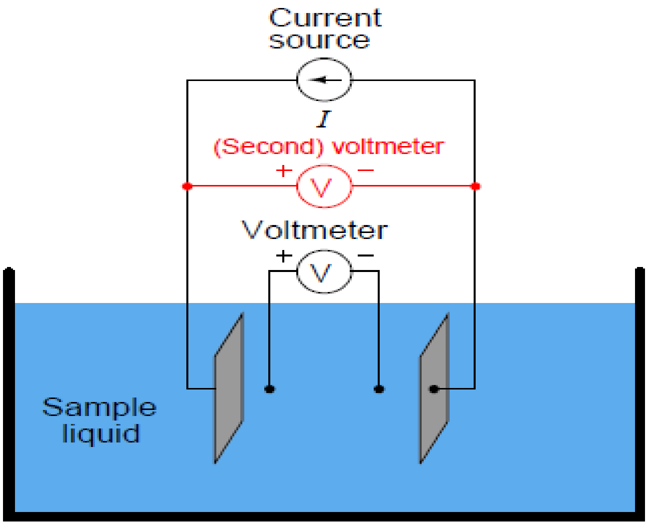


Figure 3.5 Four-electrodes conductivity measurement employ an excitation electrode voltmeter

Any form of electrode fouling will cause this secondary voltage measurement to rise, thus providing an indicator that instrument technicians may use for predictive maintenance (telling them when the probes need cleaning or replacement). Meanwhile, the primary voltmeter will do its job of accurately measuring liquid conductivity so long as the current source is still able to output its normal amount of current.

3.2.5 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, because PH has a great effect on the outcome of many chemical processes. Food processing, water treatment, pharmaceutical production, steam generation (thermal power plants), and alcohol manufacturing are just some of the industries making extensive use of PH measurement (and control). PH is also a significant factor in the corrosion of metal pipes and vessels carrying aqueous (water-based) solutions, so PH measurement and control are important in the life-extension of these capital investments.

In order to understand PH measurement, you must first understand the chemistry of PH.

Hydrogen ion activity in aqueous (water-solvent) solutions is a very important parameter for a wide variety of industrial processes. A number of reactions important to chemical processing are inhibited or significantly slowed if the hydrogen ion activity of a solution does not fall within a narrow range. Hydrogen ions are always measured on a logarithmic scale, and referred to as PH. Free hydrogen ions (H^+) are rare in a liquid solution, and are more often found attached to whole water molecules to form a positive ion called hydronium (H_3O^+). However, process control professionals usually refer to these positive ions simply as “hydrogen” even though the truth is a bit more complicated. PH is mathematically defined as the negative common logarithm of hydrogen ion activity in a solution. Hydrogen ion activity is expressed as a molarity (number of moles of active ions per liter of solution), with “pH” being the unit of measurement for the logarithmic result:

$PH = -\log [H^+]$…………………………………………………………(3.6)

For example, an aqueous solution with an active hydrogen concentration of 0.00044 M has a pH value of 3.36 PH. Water is a covalent compound, and so there is little separation of water molecules in liquid form. Most of the molecules in a sample of pure water remain as whole molecules (H_2O) while a very small percentage ionize into positive hydrogen ions (H^+) and negative hydroxyl ions (OH^-). The mathematical product of hydrogen and hydroxyl ion molarity in water is known as the ionization constant (Kw), and its value varies with temperature:

$Kw = [H^+] \times [OH^-]$……………………………………………………….(3.7)

At 25 degrees Celsius (room temperature), the value of Kw is very nearly equal to $1x10^{-14}$. Since each one of the water molecules that does ionize in this absolutely pure water sample separates into exactly one hydrogen ion (H^+) and one hydroxyl ion, $(OH^-)$the molarities of hydrogen and hydroxyl ions must be equal to each other. The equality between hydrogen and hydroxyl ions in a pure water sample means that pure water is neutral, and that the molarity of hydrogen ions is equal to the square root of Kw:

$[H^+] = \sqrt{k_w} = \sqrt{1x10^{-14}} = 1x10^{-7}$…………………………………(3.8)

Since we know PH is defined as the negative logarithm of hydrogen ion activity, and we can be assured all hydrogen ions present in the solution will be “active” since there are no other positive ions to interfere with them, the pH value for water at 25 degrees Celsius is:

pH of pure water at $25°C = -\log(1x10^{-7}) = 7.0$ PH…………….……..(3.9)

As the temperature of pure water sample changes, the ionization constant changes as well. Increasing temperature causes more of the water molecules to ionize into H+ and OH− ions, resulting in a larger Kw value. The following table shows Kw values for pure water at different temperatures:

Table 3.1 Kw value for pure water at different temperature

Temperature	Kw
0℃	$1.139 x 10^{-15}$
5℃	$1.846 x 10^{-15}$
10℃	$2.920 x 10^{-15}$
15℃	$4.505 x 10^{-15}$
20℃	$6.809 x 10^{-15}$
25℃	$1.008 x 10^{-14}$
30℃	$1.469 x 10^{-14}$
35℃	$2.089 x 10^{-14}$
40℃	$2.919 x 10^{-14}$
45℃	$4.018 x 10^{-14}$
50℃	$5.474 x 10^{-14}$
55℃	$7.296 x 10^{-14}$
60℃	$9.614 x 10^{-14}$

This means that while any pure water sample is neutral (an equal number of positive hydrogen ions and negative hydroxyl ions) at any temperature, the PH value of pure water actually changes with temperature, and is only equal to 7.0 PH at one particular (“standard”) temperature: 25℃. If we add an electrolyte to a sample of pure water, (at least some of) the molecules of that electrolyte will separate into positive and negative ions. If the positive ion of the electrolyte happens to be a hydrogen ion (H^+), we call that electrolyte an acid. If the negative ion of the electrolyte happens to be a hydroxyl ion (OH^-), we call that electrolyte a caustic, or alkaline, or base. Some common acidic and alkaline substances are listed here, showing their respective positive and negative ions in solution. Sulfuric acid is an acid (produces H^+ in solution):

$H_2SO_4 \rightarrow 2H^+ + SO_4{}^{-2}$……………………………………………(3.10)

Nitric acid is an acid (produces H^+ in solution):

$HNO_3 \rightarrow H^+ + NO_3{}^-$………………………………………………(3.11)

Potassium hydroxide is a caustic (produces OH− in solution):

$KOH \rightarrow K^+ + OH^-$…………………………………………………(3.12)

Sodium hydroxide is a caustic (produces OH− in solution):

$NaOH \rightarrow Na^+ + OH^-$…………………………………………………..(3.13)

Calcium hydroxide is a caustic (produces OH− in solution):

$Ca(OH)_2 \rightarrow Ca^{+2} + 2OH^-$…………………………………………….(3.14)

When an acid substance is added to water, some of the acid molecules dissociate into positive hydrogen ions (H^+) and negative ions (the type of negative ions depending on what type of acid it is). This increases the molarity of hydrogen ions (the number of moles of (H^+) ions per liter of solution). The addition of hydrogen ions to the solution also decreases the molarity of hydroxyl ions (the number of moles of (OH^-) ions per liter of solution) because some of the water's (OH^-)ions combine with the acid's (H^+) ions to form deionized water molecules (H_2O). If an alkaline substance (otherwise known as a caustic or a base) is added to water, some of the alkaline molecules dissociate into negative hydroxyl ions $(OH^-)$and positive ions (the type of positive ions depending on what type of alkaline it is). This increases the molarity of (OH^-)ions in the solution, as well as decreases the molarity of hydrogen ions (again, because some of the caustic's (OH^-)ions combine with the water's (H^+) ions to form deionized water molecules, H_2O). The result of this complementary effect (increasing one type of water ion, decreasing the other) keeps the overall ionization constant relatively constant, at least for dilute solutions. In other words, the addition of an acid or a caustic may change (H^+), but it has little effect on Kw [5].

A simple way to envision this effect is to think of a laboratory balance scale, balancing the number of hydrogen ions in a solution against the number of hydroxyl ions in the same solution. When the solution is pure water, this imaginary scale is balanced (neutral), with (H^+) = (OH^-) Adding an acid to the solution tips the scale one way, while adding a caustic to the solution tips it the other way If an electrolyte has no effect on the hydrogen and hydroxyl ion activity of an aqueous solution, we call it a salt. The following is a list of some common salts, showing their respective ions in solution:

Potassium chloride is a salt (produces neither (H^+) nor (OH^-) in solution):

$KCL \rightarrow K^+ + CL^-$……………………………………………………….(3.15)

Sodium chloride is a salt (produces neither (H^+) nor (OH^-) in solution):

$NaCL \rightarrow Na^+ + CL^-$……………………………….………………..(3.16)

The addition of a salt to an aqueous solution should have no effect on PH, because the ions created neither add to nor take away from the hydrogen ion activity. Acids and caustics tend to neutralize one another, the hydrogen ions liberated by the acid combining (and canceling) with the hydroxyl ions liberated by the caustic. This process is called PH neutralization, and it is used extensively to adjust the PH value of solutions.

3.2.6 PH meter

The most common PH measurement method used in continuous process (e.g. boiler water treatment) 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:

$$V = \frac{RT}{nF} \ln\left(\frac{C_1}{C_2}\right) \quad \text{……………………………………………………..(3.17)}$$

Where,

V : Voltage produced across membrane due to ion exchange, in 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)

The Nernst equation predicts a greater voltage developed across the thickness of a membrane as the concentrations on either side of the membrane differ to a greater degree. If the ionic concentration on both sides of the membrane is equal, no Nernst potential will develop.

In the case of PH measurement, the Nernst equation describes the amount of electrical voltage developed across a special glass membrane due to hydrogen ion exchange between the process liquid solution and a buffer solution inside the bulb formulated to maintain a constant PH value of 7.0 PH. Special PH-measurement electrodes are manufactured with a closed end made of this glass, a small quantity of buffer solution contained within the glass bulb.

Any concentration of hydrogen ions in the process solution differing from the hydrogen ion concentration in the buffer solution ($[H^+]$ =$1x10^{-7}$ M) will cause a voltage to develop across the thickness of the glass. Thus, a standard PH measurement electrode produces no potential when the process solution's PH value is exactly 7.0 PH (equal in hydrogen ion activity to the buffer solution trapped within the bulb).

The glass used to manufacture this electrode is no ordinary glass. Rather, it is specially manufactured to be selectively permeable to hydrogen ions. If it were not for this fact, the electrode might generate voltage as it contacted any number of different ions in the solution. This would make the electrode non-specific, and therefore useless for PH measurement. Manufacturing processes for PH-sensitive glass are highly guarded trade secrets. There seems to be something of an art to the manufacture of an accurate, reliable, and long-lived PH electrode. A variety of different measurement electrode designs exist for different process applications, including high pressure and high temperature services [5].

The schematic diagram of PH meter is illustrated in the following figure 3.6 below.

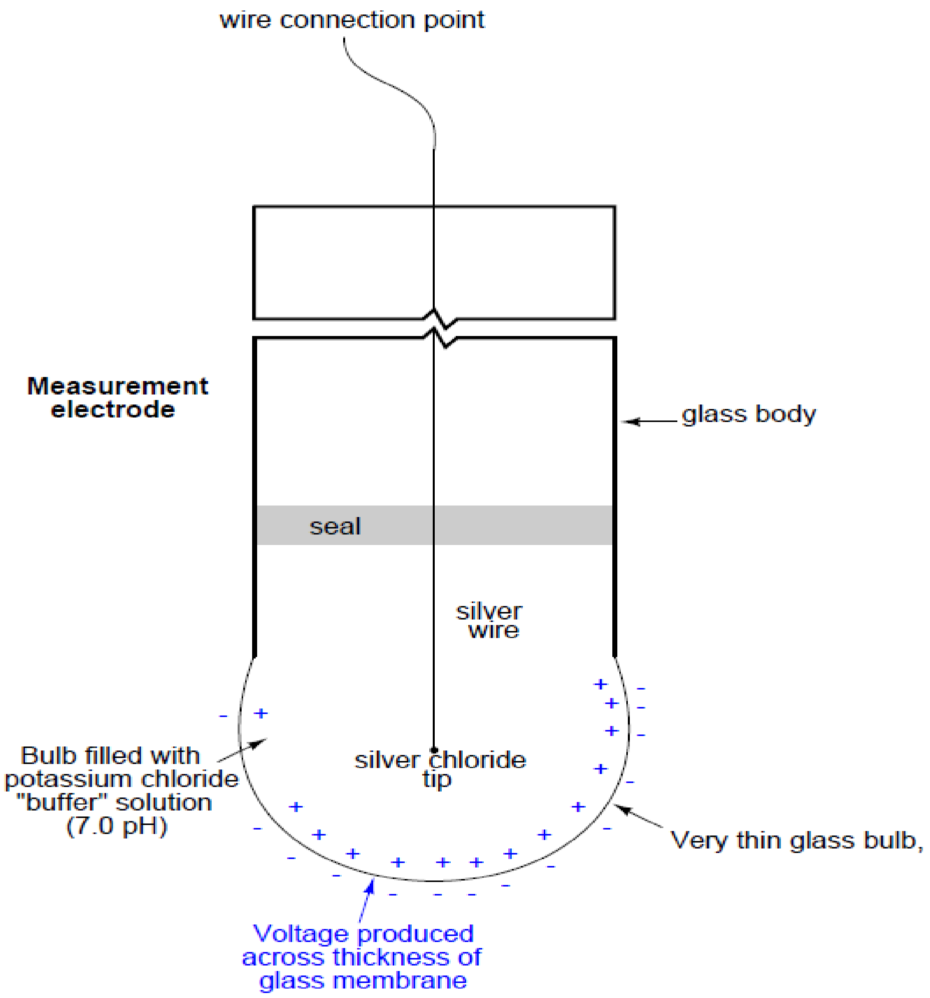


Figure 3.6: PH electrode

Actually measuring the voltage developed across the thickness of the glass electrode wall, however, presents a bit of a problem: while we have a convenient electrical connection to the solution inside the glass bulb, we do not have any place to connect the other terminal of a sensitive voltmeter to the solution outside the bulb. In order to establish a complete circuit from the glass membrane to the voltmeter, we must create a zero-potential electrical junction with the process solution. To do this, we use another special electrode called a reference electrode immersed in the same liquid solution as the measurement electrode (figure3.7).

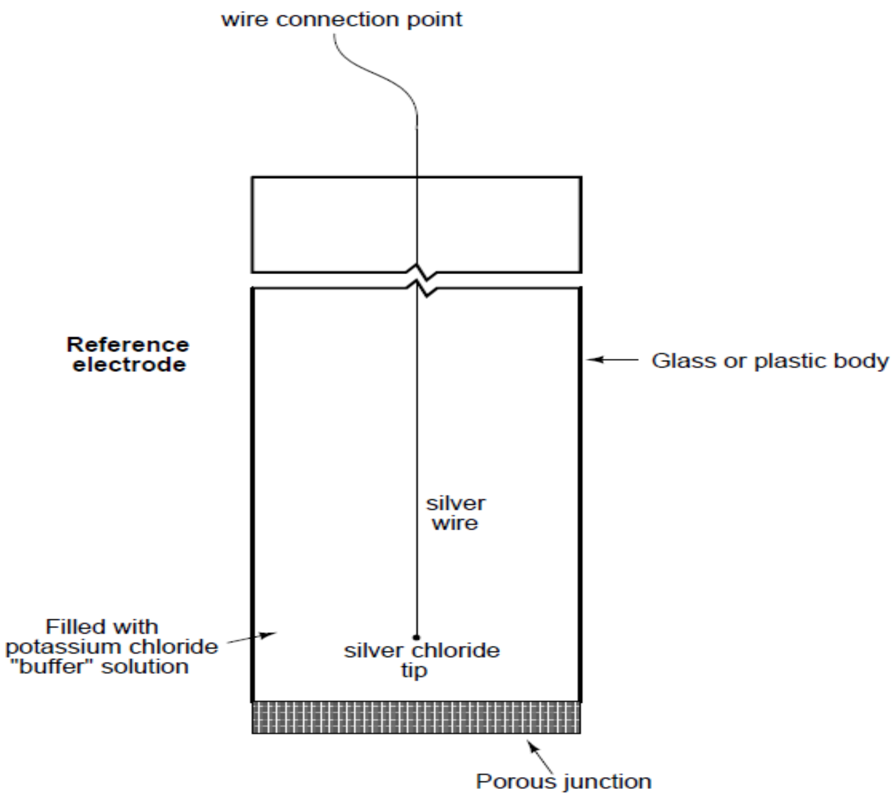


Figure 3.7: PH reference electrode

Together, the measurement and reference electrodes provide a voltage generating element sensitive to the PH value of whatever solution they are submerged in as shown in figure 3.8.

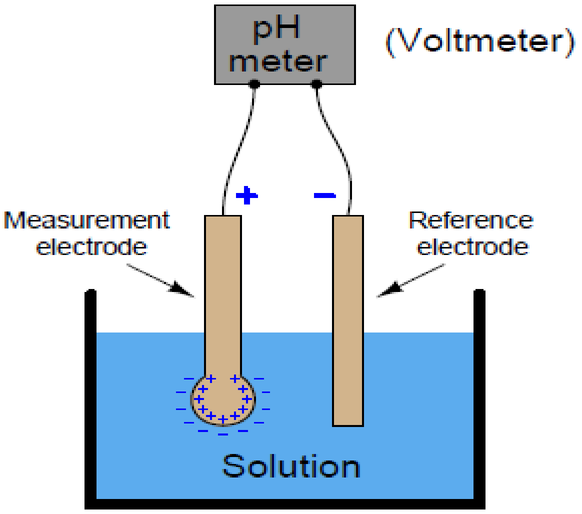


Figure 3.8: PH meter submerged in solution

The most common configuration for modern PH probe sets is what is called a combination electrode, which combines both the glass measurement electrode and the porous reference electrode in a single unit. Figure 3.9 shows a typical industrial combination PH electrode:

Figure 3.9: Typical industrial combination PH electrode

The red-colored plastic cap on the right-hand end of this combination electrode covers and protects a gold-plated coaxial electrical connector, to which the voltage-sensitive PH indicator (or transmitter) attaches.

Another model of PH probe appears in the next photograph. Here, there is no protective plastic cap covering the probe connector, allowing a view of the gold-plated connector bars (figure 3.10).

Figure 3.10: PH probe without protective plastic cap covering the probe connector to view gold-plated connector bars

The voltage produced by the measurement electrode (glass membrane) is quite modest. A calculation for voltage produced by a measurement electrode immersed in a 6.0 pH solution shows this. First, we must calculate hydrogen ion concentration (activity) for a 6.0 pH solution, based on the definition of pH being the negative logarithm of hydrogen ion molarity:

$\mathrm{PH} = -\log(\mathrm{H}^+)$

$6 = -\log(\mathrm{H}^+)$

$-6 = \log(\mathrm{H}^+)$

$10^{-6} = 10^{\log(\mathrm{H}^+)}$……………………………………..……………(3.18)

$10^{-6} = \mathrm{H}^+$

$\mathrm{H}^+ = 1\mathrm{x}10^{-6}\mathrm{M}$

This tells us the concentration of hydrogen ions in the 6.0 PH solution (hydrogen ion concentration being practically the same as hydrogen ion activity for dilute solutions). We know that the buffer solution inside the glass measurement bulb has a stable value of 7.0 PH (hydrogen ion concentration of $1\mathrm{x}10^{-7}\mathrm{M}$, or 0.0000001 moles per liter), so all we need to do now is plug these values into the Nernst equation to see how much voltage the glass electrode should generate. Assuming a solution temperature of $25°\mathrm{C}$ (298.15 K) and knowing that n in the Nernst equation will be equal to 1 (since each hydrogen ion has a single-value electrical charge):

$$\mathrm{V} = \frac{\mathrm{RT}}{\mathrm{nF}} \ln\left(\frac{\mathrm{C}_1}{\mathrm{C}_2}\right)$$

$\mathrm{V} = \frac{8.315\mathrm{x}298.15}{1\mathrm{x}96485} \ln\left(\frac{1\mathrm{x}10^{-6}}{1\mathrm{x}10^{-7}}\right)$……………..………………………………(3.19)

$\mathrm{V} = 59.17\mathrm{mV}$

If the measured solution had a value of 7.0 PH instead of 6.0 PH, there would be no voltage generated across the glass membrane since the two solutions' hydrogen ion activities would be equal. Having a solution with one decade (ten times more: exactly one "order of magnitude") greater hydrogen ions activity than the internal buffer solution produces 59.17 millivolts at 25 degrees Celsius. If the PH were to drop to 5.0 (two units away from 7.0 instead of one unit), the output voltage would be double: 118.3 millivolts. If the solution's PH value were more alkaline than the internal buffer (for example, 8.0 PH), the voltage generated at the glass bulb would be the opposite polarity (e.g. 8.0 PH = -59.17mV; 9.0PH = -118.3mV, etc.).

Table 3.2 The Values of pH at Different Hydrogen Ion Concentration

Hydrogen ion activity	pH value	Probe voltage (at 25°C)
$1\text{x}10^{-3}\text{M} = 0.001\ \text{M}$	3.0 pH	236.7 mV
$1\text{x}10^{-4}\text{M} = 0.0001\ \text{M}$	4.0 pH	177.5 mV
$1\text{x}10^{-5}\text{M} = 0.00001\ \text{M}$	5.0 pH	118.3 mV
$1\text{x}10^{-6}\text{M} = 0.000001\ \text{M}$	6.0 pH	59.17 mV
$1\text{x}10^{-7}\text{M} = 0.0000001\ \text{M}$	7.0 pH	0 mV
$1\text{x}10^{-8}\text{M} = 0.00000001\ \text{M}$	8.0 pH	-59.17 mV
$1\text{x}10^{-9}\text{M} = 0.000000001\ \text{M}$	9.0 pH	-118.3 mV
$1\text{x}10^{-10}\text{M} = 0.0000000001\ \text{M}$	10.0 pH	-177.5 mV
$1\text{x}10^{-11}\text{M} = 0.00000000001\ \text{M}$	11.0 pH	-236.7 mV

The logarithmic nature of the Nernst equation means that pH probes – and in fact all Potentiometric sensors based on the same dynamic of voltage produced by ion exchange across a membrane – have astounding rangeability: they are capable of representing a wide range of conditions with a modest signal voltage span.

3.3 Some Detection Methods of Sugar Contamination

Several devices for the continuous monitoring of sugar contamination have been proposed and several have been tested or used with success in other sugar mills. A description of these instruments follows.

3.3.1 Total organic carbon

The principle of this instrument is the conversion of organic carbon to carbon dioxide by irradiation with ultraviolet light after addition of persulphate. The quantity of carbon dioxide is measured by means of an infrared detector and the output signal is proportional to the organic content of the sample [1]. It is claimed to be robust and reliable enough to survive in any industrial application. Reaction time could be reduced to about one minute per sample stream, depending on the accuracy required

3.3.2Auto-analyzer

In this apparatus water samples containing trace amounts of sugar are pumped into a manifold where mixing with the reagents (resorcinol/hydrochloric acid) occurs. The mixture is then continuously pumped into a heating bath where color development occurs. The color, which is proportional to the sugar content, is measured in a colorimeter. An advantage over other designs is that the reaction is sugar specific.

A disadvantage is that the reaction time can vary from 5 to 15 minutes, depending on the reagents used and the accuracy required. Auto-analyzers have been used successfully to monitor condensates for boiler feed, and descriptions of two types of auto-analyzer used in monitoring refinery wastewaters are given by Fowler (1977). Schaffler (1978) described the use of an auto-analyzer for monitoring entrainment. Auto-analyzers have worked well in a clean laboratory where supervision is good, but they are not suited to on-line monitoring in the harsh factory environment.

3.3.3 Flame photometer

Flame photometers have been in use at several sugar mills for many years and have worked well provided they have been well maintained and serviced; the use of a flame photometer for monitoring entrainment was described by Dale and Lamusse (1977). However the instrument does not detect sucrose directly but measures the concentration of potassium Ions that are assumed always to be present with the sugar. For this reason they are considered to be only slightly better than conductivity monitors [1].

3.3.4 Fluorescence

Fluorescence-based technology provides a novel approach for continuously monitoring thin juice in an evaporator condensate stream. Though sugar itself does not fluoresce, research shows that the non-sugars in thin juice do have fluorescent properties. By monitoring the fluorescence of the evaporator condensate on-line, it is possible to detect real-time sugar shot events [7].

The basic principle of fluorescence is characterized by excitation wavelength, emission wavelength and fluorescence intensity. Background signals exist for all analytical techniques, and are not unique to fluorescence. However, the advantage with this technique is that fluorescence is a very selective method and few compounds fluoresce intensely at the same excitation and emission wavelengths [7].

Figure 3.11 provides a rough schematic on fluorescence detection. A light source is used to provide the excitation energy for the water sample fluorescent molecule flowing through the flow cell carefully selected filters is used for specific wavelengths. The fluorescent molecule in the condensate stream absorbs the electromagnetic energy, reaches the first excited singlet state and then decays to the ground state causing fluorescence emission of a photon as illustrated in Figure 3.12. The wavelength of the emitted radiation is independent of the excitation wavelength, and is detected by a photomultiplier. At low concentrations, the fluorescence intensity is directly proportional to concentration [7].

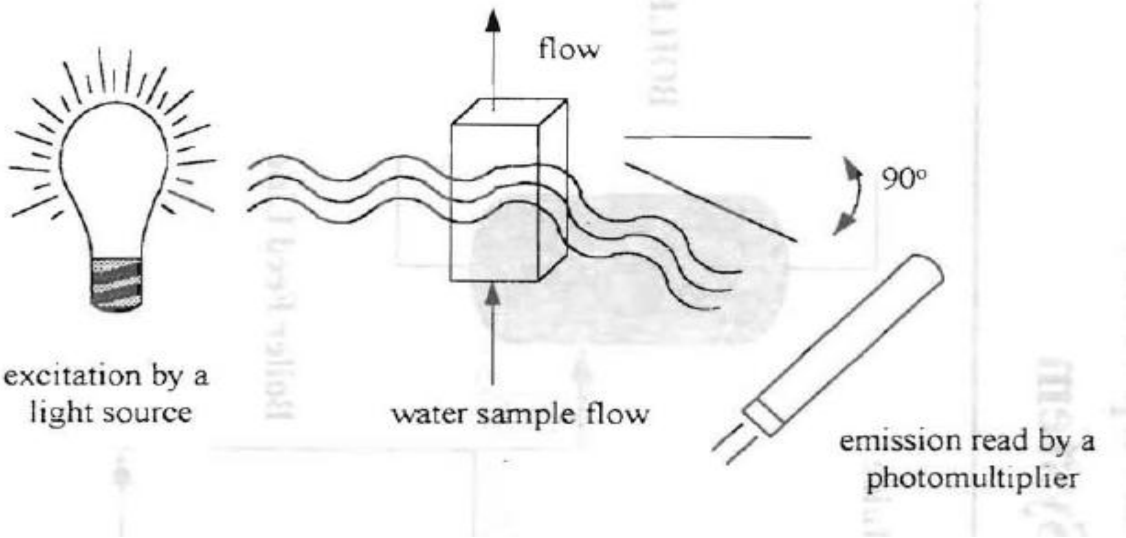


Figure 3.11 Schematic diagram of fluorescence detection

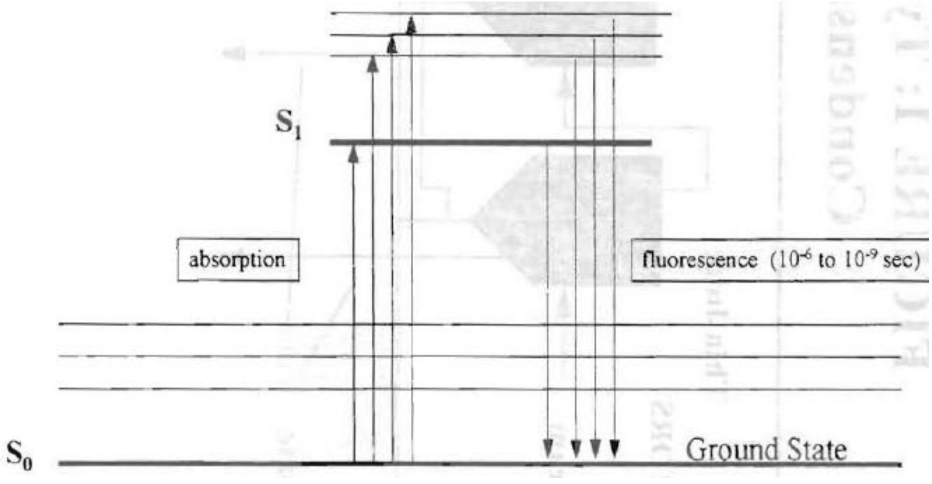


Figure 3.12 Energy level diagram

3.3.5 Conductivity monitors

The use of conductivity monitors as described by Cargill (1962) and Douglas (1962) has become almost universal, even though it is appreciated that the conductivity of a solution is an imperfect measure of the sugar content. The suitability of such a monitor depends on the presence of other impurities in the form of various salts which always accompany the sugar. The relationship between sucrose content and conductivity is highly variable because it depends on the nature and quantity of these salts. This in turn depends on the source of the contamination and on the constituents of the cane, which can vary throughout the season. In a typical raw sugar mill the conductivity monitoring system can be made to work satisfactorily as a sugar detector. Sugar contamination can be avoided using dumping system which will be discussed in chapter four.

CHAPTER FOUR

DESIGN OF MAIN AUTOMATIC SYSTEMS

4.1 Introduction

this chapter describe the essential control systems which should be designed to ensure healthy supplying of water to boilers at all the time, those systems are used in most steam power plant water treatment specially those in sugar factories, the first system is “automatic blow down” which concern with maintaining the level of TDS in the boiler water at desire value, the second one is used to maintain the “PH” of boiler water at specific range, and the last system is “dumping system” this is required to divert the contaminated condensate water (return from process) to the wastage water tank.

4.2 Boiler Water Sampling System

This system is required for continuous measuring of boiler water PH and conductivity which are considered important parts for system automation. Some performance factors such as: Instrument measuring range, accuracy, reliability and routine maintenance requirement were considered when selecting instruments. Based on these factors the following instrument has been chosen:

- Eight PH analyzer with the following features:
  Measuring range 0 to 14PH.
  Accuracy: ± 0.01PH.
  Output signal: two isolated 4-20mA analogue signals.
  Power supply: 220V AC.
  Calibration: monthly.
- Eight conductivity analyzer:
  Measuring range 1 to 1000 $\mu s/cm$.

Accuracy: ±1% of reading.

Output signal: two isolated 4-20mA analogue signals.

Power supply: 220V AC.

Calibration: annually.

Figure 4.1 shows the boiler sampling system.

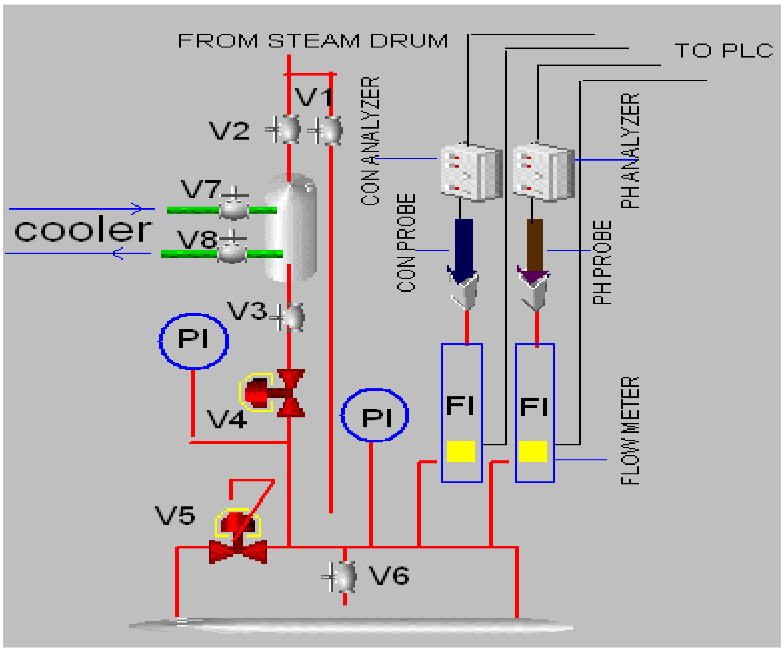


Figure (4.1) Sampling system

Where V is Valve, PI is pressure indicator, TI is temperature indicator, FI is flow indicator

The following areas were considered and emphasized when designing the system:

4.2.1 Sample cooler

The sample cooler is a shell and tube heat exchanger. The cooler is used to cool the steam drum water sample to 25°C using the closed cooling water the sample temperature is usually 300°C. The best temperature for conductivity and PH measurement is 25°C. Although the analyzers have an automatic temperature compensation functions.

As can be seen from Figure 4.1 V7 and V8 are the closed cooling water isolation valves. The flow of closed cooling water can be manually controlled using V7 to regulate the sample temperature after the cooler. The closed cooling water flow rate does not need to be adjusted regularly because the inlet sample temperature is quite stable. The closed cooling water flow rate is displayed by the flow indicator.

4.2.2 Boiler water sample loop

Figure 4.1 shows the condensate sample loop components. When the system is put into service, blowdown valve V1 is used to flush the condensate sample line ahead of the cooler until the sample is clean. V1 remains shut during the normal operation. Isolation valve V2 is used to isolate the sample and is open during normal operation kg/cm^2.

Pressure-reducing valve V4 is used to reduce the sample pressure from 30 kg/cm^2 to 2 kg/cm^2 which is the nominal pressure for the analyzer sensors. The sample pressure after the cooler is displayed on pressure gauge PI. Valve V6 is used to take a manual sample for laboratory purposes. In addition, V6 can also be used to flush the sample line before the analyzers when the system is put into service.

4.2.2.1 High pressure protection

The adjustable backpressure regulator V5 is used to stabilize the analyzer inlet pressure. As shown in Figure 4.1, if the sample pressure exceeds 2 kg/cm^2 (current setpoint) the regulator V5 opens to divert the excess sample to the drain. The higher the pressure, the more the regulator opens.

4.2.2.2 High temperature protection

Thermal shutoff valve (TSV) V4, is installed immediately after the sample cooler as shown in Figure 4.1. The TSV is a self-contained mechanical device that requires no external electrical or air supply. The sensor/actuator is directly exposed to the sample. If the sample temperature after the cooler exceeds 49°C, the TSV will automatically shut to isolate the sample and protect the analyzer sensors from high temperature damage. The TSV can be reopened manually after a trip by pushing the button on top of the TSV. Once the TSV is closed, the pressure in the sample line will rise. And if the pressure exceeds 2 kg/cm^2, the back pressure regulator V5 will open to maintain the pressure at 2 kg/cm^2 by diverting the sample to drain.

4.2.2.3 Low flow detection

Every analyzer in the system must have an adequate sample continuously flowing through the analytical sensor in order to guarantee that the data sent to the PLC is accurate. Each analyzer is therefore equipped with a sample flowmeter and low flow ring sensor as shown in Figure 4.1. The flowmeter ring sensor has a bistable switching action when the float falls to the trigger level. The relay remains de-energized even if the float drops below the sensor. The relay re-energizes as soon as the float crosses the trigger level in the upward direction and moves into the normal operating range.

The sample flows upwards through the flowmeter. The position of the ball float indicates the sample flow rate. The sample flow can be adjusted using the knob at the top of the meter. The sample flow rate is usually kept between 150 and 200 ml/min. The trigger level of the ring sensor is 100ml/min. If the sample flow rate falls below 100 ml/min, the ball float will reach the ring sensor de-energizing the relay and generating a low sample flow alarm in the plc. The following figure 4.2 shows the system for all boilers.

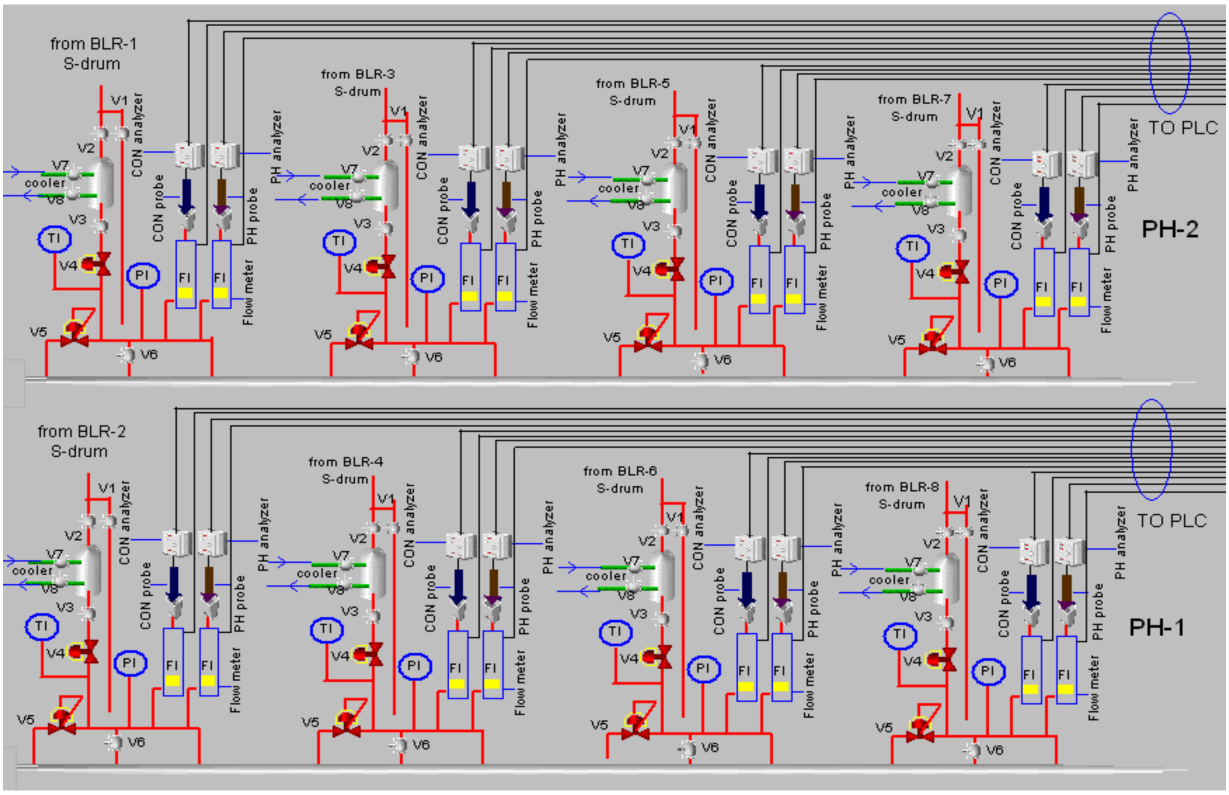


Figure 4.2: Boilers water sampling system

4.3 Control Systems Design:

After measuring the PH, and conductivity we are going to design individual control system, of boiler water plant.

4.3.1 Automatic blow down

When water is boiled and steam is generated, any dissolved solids contained in the water remain in the boiler. If more solids are put in with the feed water, they will concentrate and may eventually reach a level where their solubility in the water is exceeded and they deposit from the solution. Above a certain level of concentration, these solids encourage foaming and cause carryover of water into the steam. The deposits also lead to scale formation inside the boiler, resulting in localized overheating and reduced heat transfer; this means increased fuel consumption and decreased boiler efficiency, as well as corrosion and finally causing boiler tube failure.

It is, therefore, necessary to control the level of concentration of the total dissolved solids and this is achieved by the process of “blowdown”, where a certain volume of water is blown off and is automatically replaced by feed water - thus maintaining the optimum level of TDS in the boiler water. However, blow down can be a significant source of heat loss, if improperly carried out. In order to prevent the above mentioned problems, the TDS needs to be controlled within a certain specified limit. The maximum permissible limit of TDS is 3500 ppm, so that no boiler should be allowed to across it because of scale, foam and carryover problems.

To measure total dissolved solids in boiler water system, conductivity measurement is used for monitoring the overall TDS present in the boiler. Arise in conductivity indicates a rise in the TDS of the boiler water, approximately (TDS=0.7*conductivity).

4.3.1.1 Manual vs. automatic blowdown

Blowdown is achieved either by manual or automatic methods. In the manual method, blowdown is achieved by opening valve on the side of the steam drum (upper drum). However, this practice can be highly wasteful. As the period of blowdown is not related with either boiler steam load or feedwater purity, the TDS level in manual methods can vary greatly, causing an average TDS level much lower or greater than the normal limit. On the other hand, an automatic blowdown control system, based on TDS measurement and subsequent corrective action, can maintain a TDS level much closer to the set point, resulting in considerable fuel.

4.3.1.2 System description

The following figure 4.3 shows the system connected to the PLCs.

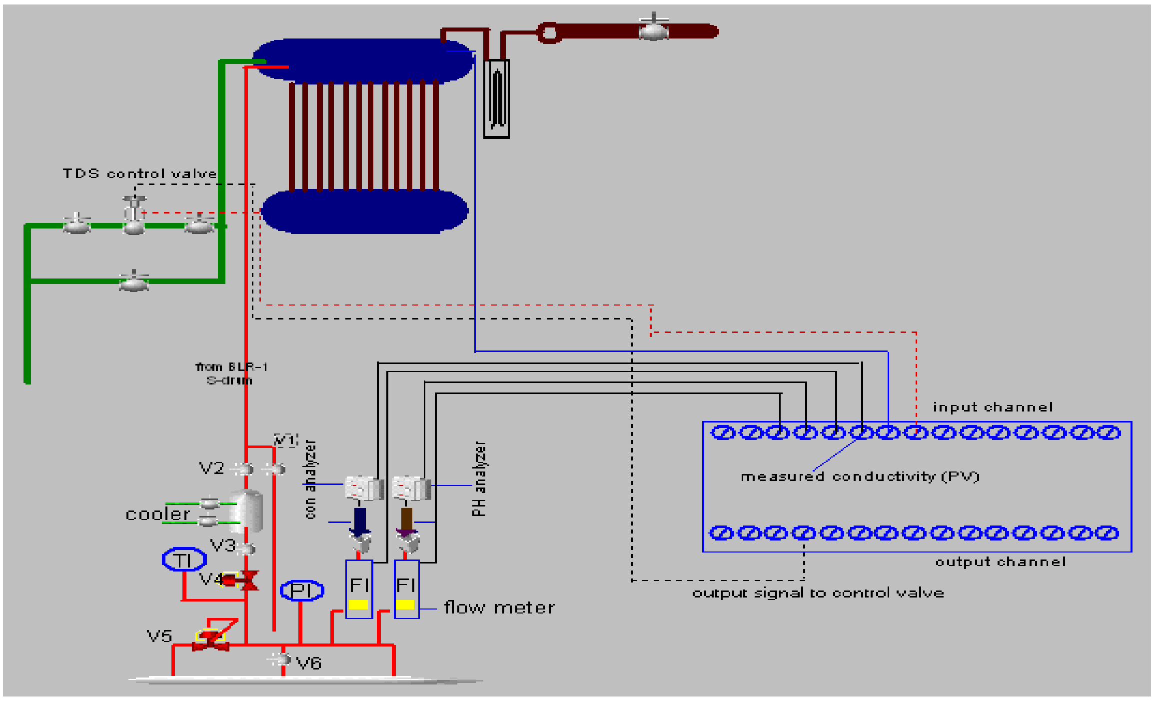


Figure 4.3: Automatic blowdown control system

The value of conductivity (PV) is measured continuously and compared with the setpoint (sp) using PID control via PLCs. When the PLCs is placed in the “run” mode, it will move the control valve to whatever position it needs to be in order to maintain a constant conductivity. If the controller senses a process variable above setpoint, it will take whatever action is necessary to bring that process variable back down to setpoint. Conversely, if the controller senses a process variable below setpoint, it will take whatever action is necessary to bring process variable up to setpoint, drum level also is an important factor as blowdown valve should not be actuated unless the drum level is normal because the first priority is to insure proper operation so blowdown valve should be closed when low level signal is received in PLCs.

System I/O:

> System inputs are eight conductivity sensors as describe above in sampling system; eight conductivity sample low flow detector and eight drum level sensors.

- System outputs are eight pneumatic control valves and one alarm common for low drum level, conductivity low, conductivity sample low flow.

Figure 4.4 shows the flow chart of the system.

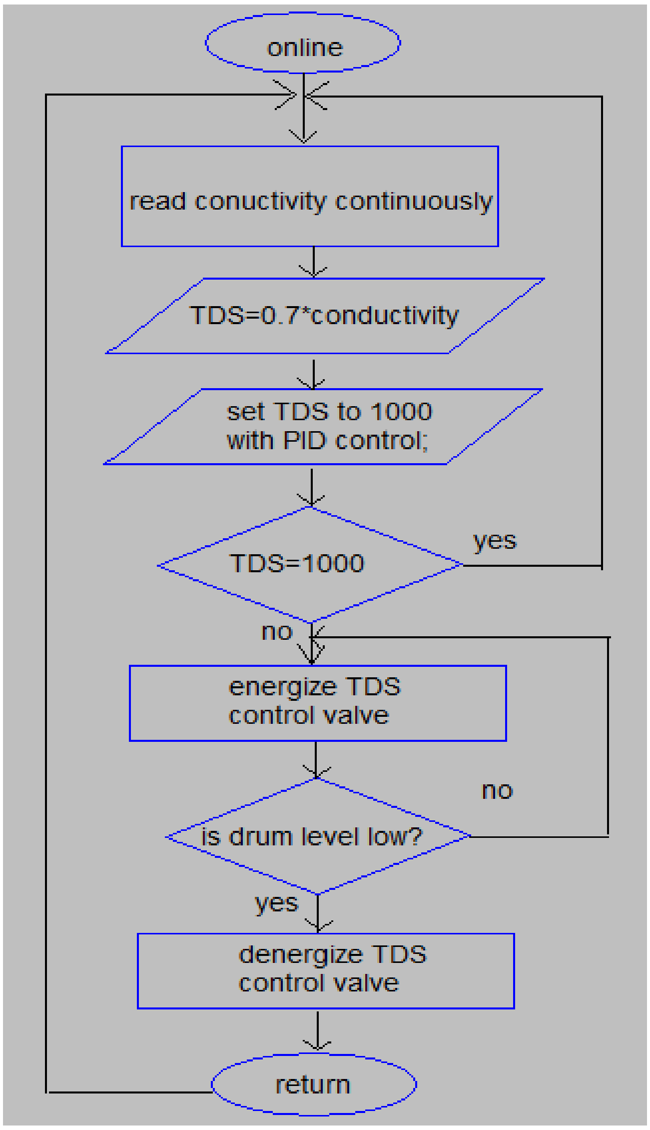


Figure 4.4: TDS control flow chart

The schematic diagram of TDS control system for the eight boilers is illustrated in the following figure 4.5.

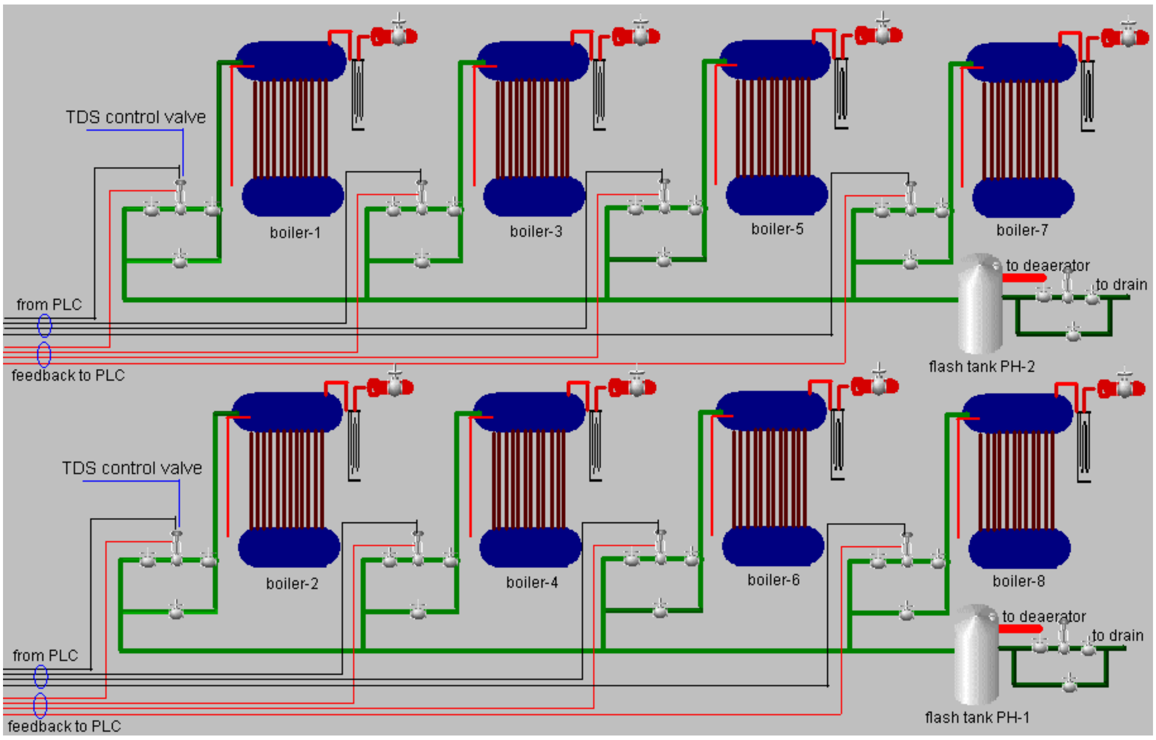


Figure 4.5: Automatic blow down for the eight boilers

4.3.2 Boiler water PH control system

This system used to keep the PH of boiler water within specific range (9.5-10.5), this system used PH analyzer to measure the PH continuously. The process of maintaining water PH is achieved by dosing caustic soda solution, the addition of caustic soda to boiler water will make the PH to rise up. There are two common caustic soda pumps for each phase, so we required solenoid valve for each boiler to dose the caustic soda for specific boiler, as caustic soda line is common for all boilers in the phase. Figure 4.6 show the flow chart of the system.

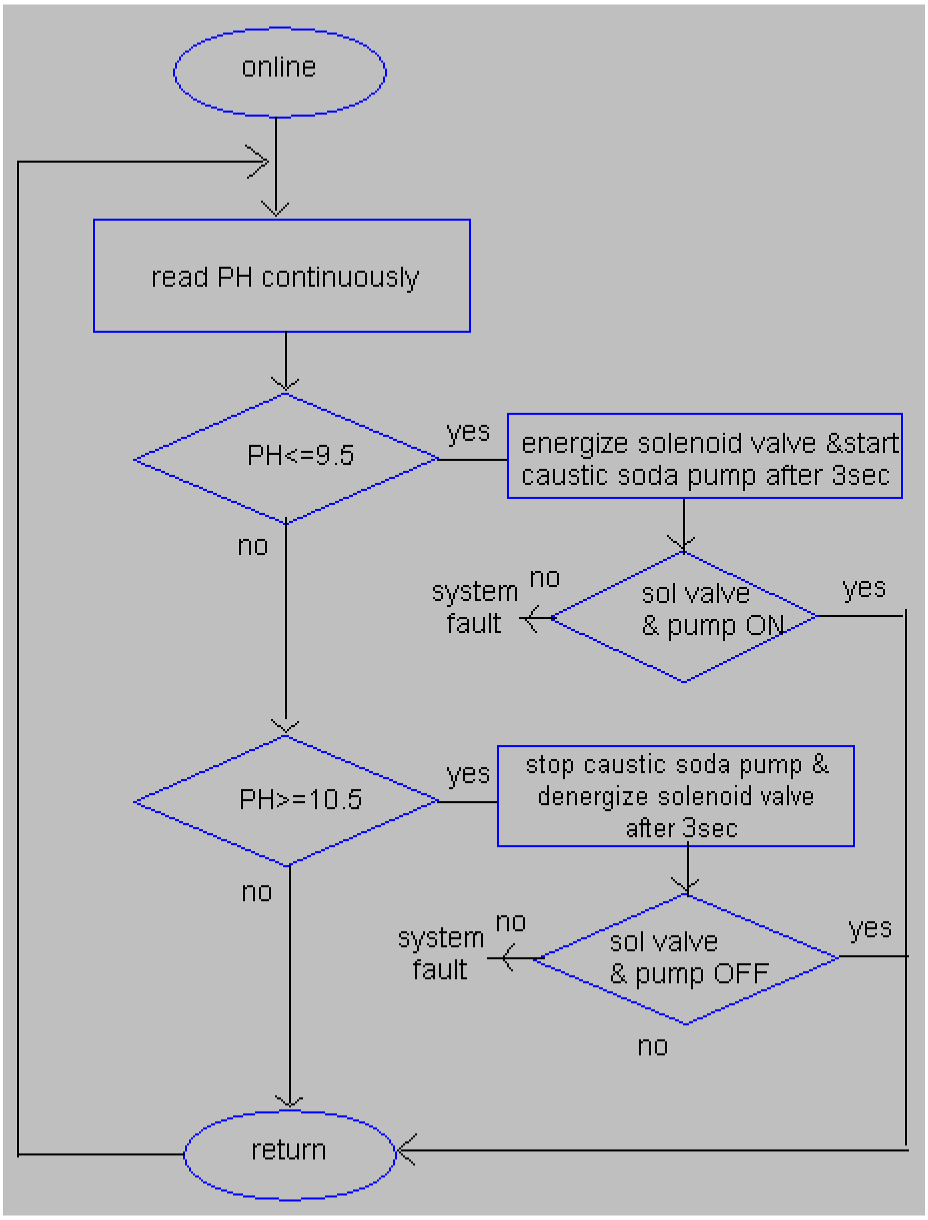


Figure 4.6: PH control flow chart

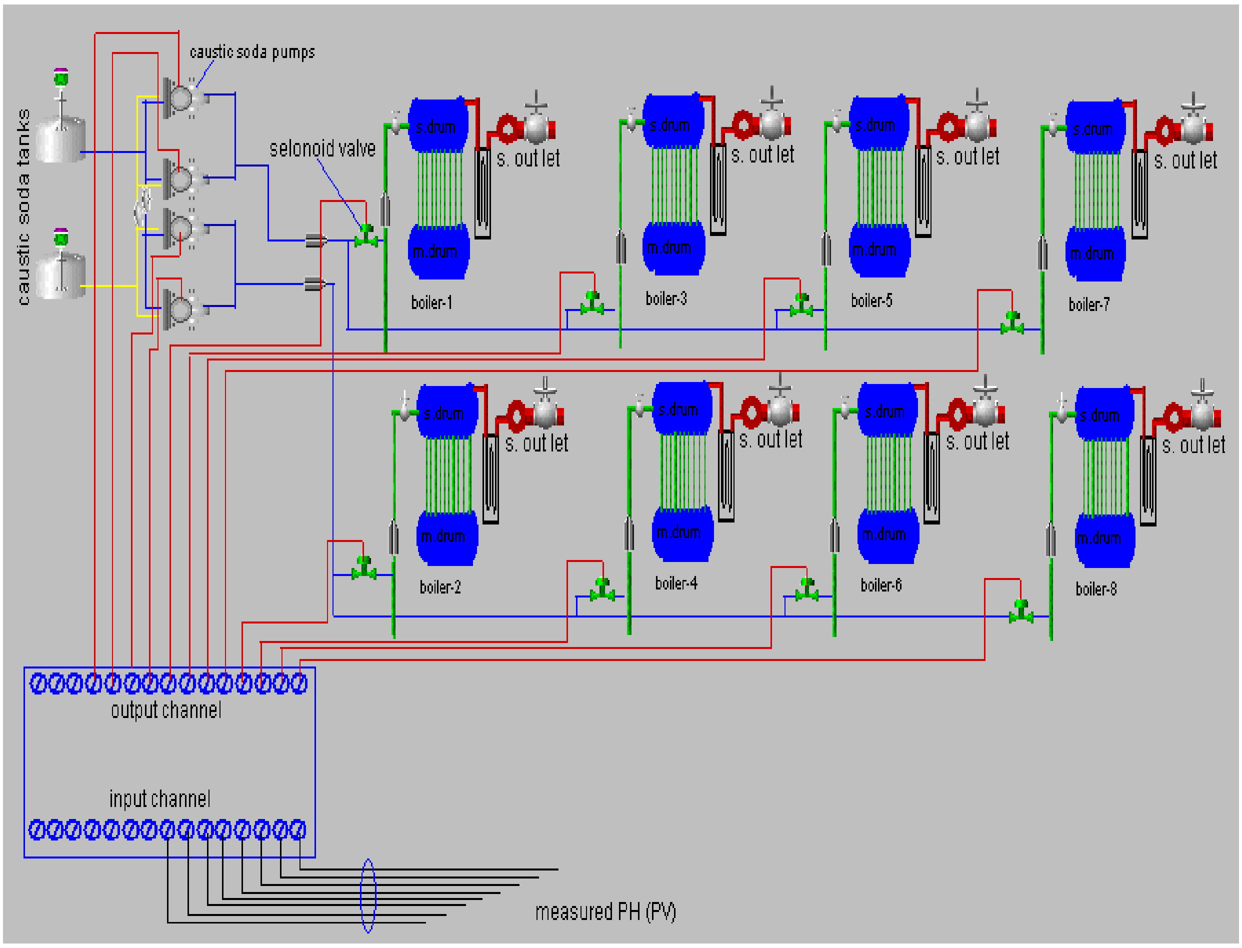


Figure 4.7: PH control system

System I/O:

- Inputs:

  1- Eight PH sensors as describe above in sampling system.

  2- Eight PH sample low flow detector.

  3- Eight digital input (N/O contacts from solenoid valves contactors).

  4- Four digital input (N/O contacts from caustic soda pumps contactors).

- Outputs:

  1- Eight solenoid valves.

  2- Four caustic soda pumps (two for each phase).

  3- one alarm common for , PH low, PH sample low flow.

On/off control strategy has been selected to start and stop the caustic soda pumps between two setpoint of PH (9.5-10.5PH), as it is not practical to maintain the value of PH constant using only one setpoint (10PH) because this required starting and stopping of caustic soda pumps continuously which lead to motor contactor failure. Figure 4.8 represents this strategy.

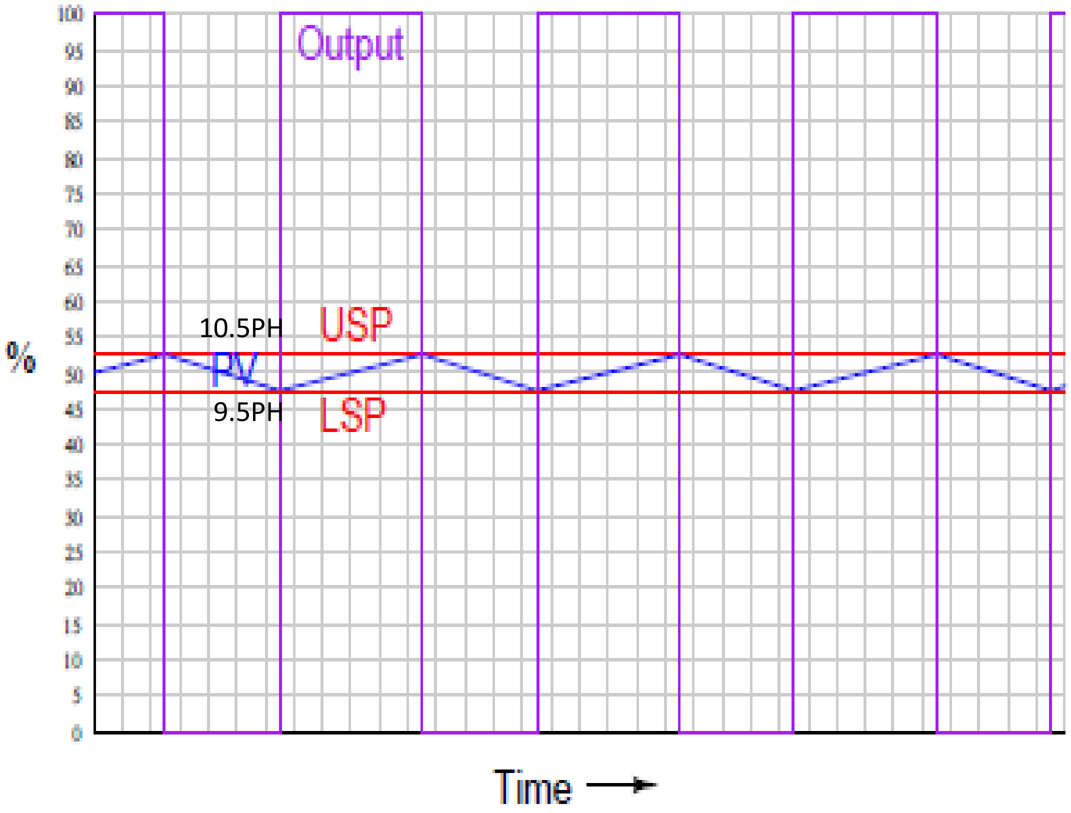


Figure 4.8: On/off control system

4.3.3 Dumping system

This system should be used to divert contaminated condensate water with sugar to wastage water tank (sweet water tank), so Introducing excess sugar into the boilers through contamination of the condensate causes a two-fold problem. The first is simply the increased level of impurities raising the risk of scale deposition in the boilers. The second and more important problem is the sometimes extreme suppression of PH which the sugar shot causes, as sugar breaks down into an organic acid in the boilers. This suppressed PH will cause corrosion of the boiler internals which could in cases be very severe. The same methodology of sampling system used in automatic blowdown can be used here to monitor the 1st condensate water return from sugar processing to boilers, in addition to conductivity measurement there is several methods can be used for sugar contamination detection such as TOC, florescence, auto analyzer,...etc as mentioned in chapter tree. All detectors produced electrical signal in term of current (4mA-20mA) or voltage (0V-10V).

The total number of evaporator is 29 units, divided as 14 units 1st , 7 units 2nd, 4 units 3rd, and 4 units 4th condensate, the 3rd, and 4th condensate are not used for boiler supply, the 2nd condensate is used for boiler supply but it is received at 2nd condensate tank (3 units) for sugar test before entering the boilers if it is clean it will be transferred to BFWT (boiler feed water tank) otherwise it will be diverted to sweet water tank, while the 1st condensate is received directly at deaerator, this source is considered the most dangerous if sugar contamination occurred; so the dumping system has been designed especially for 1st condensate source (Figure 5.9 shows the graphic of the system). There is individual detector for each body, hence if one body of them contaminated with sugar it will be automatically dumped alone, and the remaining source of other bodies will not be affected.

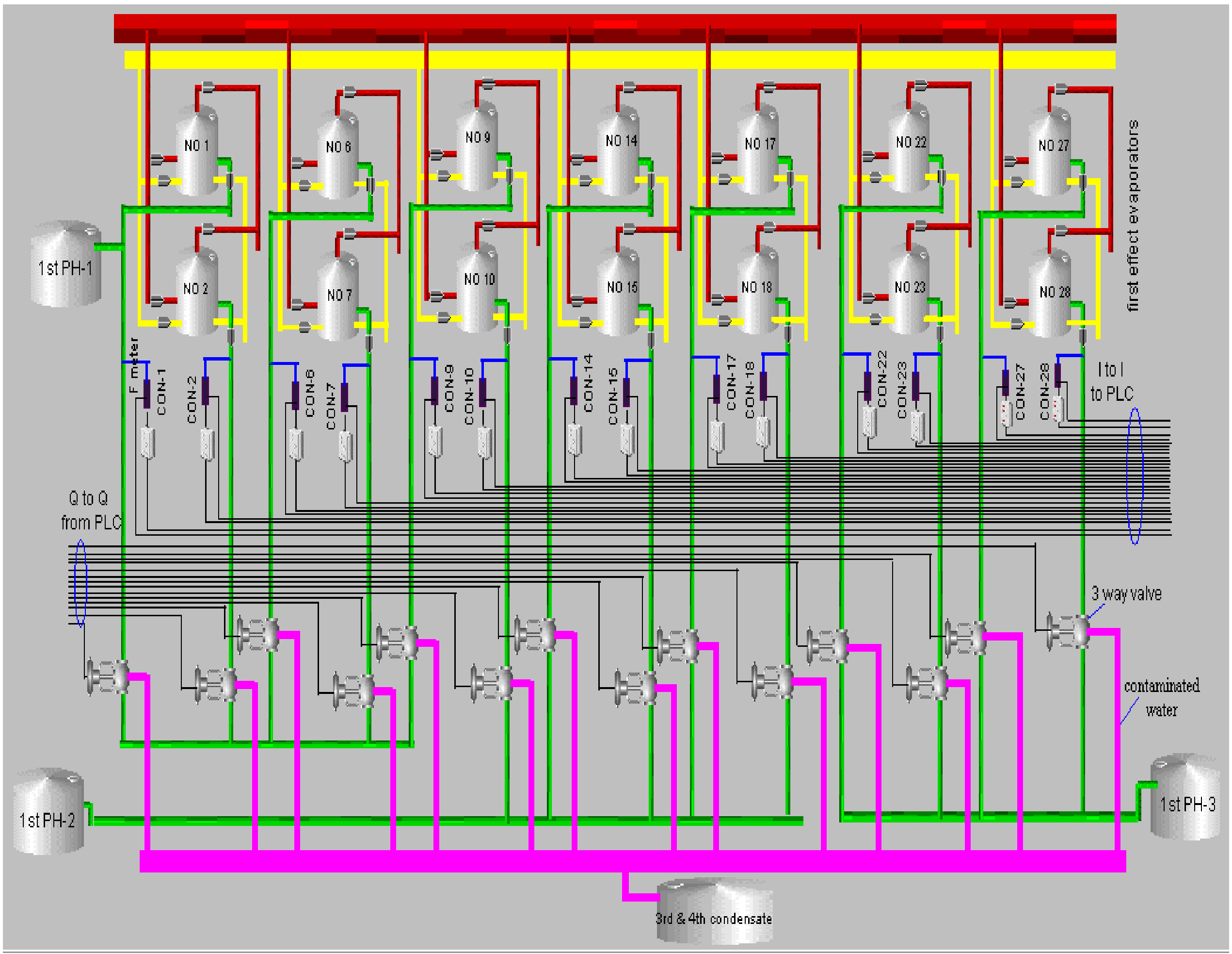


Figure 4.9: Dumping system

If we chose the conductivity analyzer as detector, the value of conductivity is measured continuously and compared with the setpoint via PLCs. If the controller senses a process variable above setpoint it will energize the 3-way control valve to divert the contaminated water to the wastage tank (sweet water tank).

System I/O:

- Inputs:
  1- Fourteen AI conductivity sensors.
  2- Fourteen DI conductivity sample low flow detector.
  3- Fourteen DI as feedback from valves coil.
- Outputs:

1- Fourteen three ways pneumatic control valves.
2- One alarm common for , conductivity low, conductivity sample low flow.

Figure 4.10 shows the flow chart of the system.

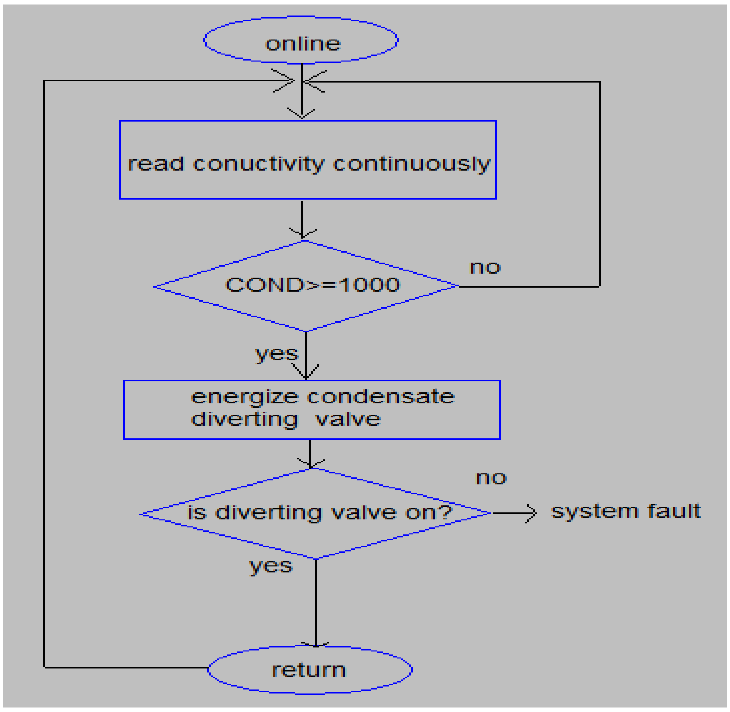


Figure 4.10: Contaminated condensate diverting system flow chart

CHAPTER FIVE

PROGRAMMING OF THE CONTROL SYSTEM

5.1 Introduction

This chapter is briefly introducing a detailed program of the main control system has been designed using Siemens simatic S7-300, also a dedicated simatic WINCC HMI graphic page (SCADA) was created for all control systems for fluent operation. In Siemens there are two types of PLCs based on the number of I/O units, single box and rack and modular types the maximum number of I/O units in the first type are 40 units and used only in small applications, while the second type (rack and modular PLCs) has a wide range of I/O units up to 5000.

5.2 Overview of STEP 7

STEP 7 is the standard software package used for configuring and programming SIMATIC programmable logic controllers. It is a part of the SIMATIC industry software. There are the following versions of the STEP 7 Standard package:

- STEP 7 Micro/DOS and STEP 7 Micro/Win for simpler stand-alone applications on the SIMATIC S7-200. This software is used to program the single box PLCs type.
- STEP 7 for applications on SIMATIC S7-300/S7-400, SIMATIC M7-300/M7-400, and SIMATIC C7 with a wider range of functions, and used to program rack & modular PLCs type.

5.2.1 System configuration

The term "configuring" refers to the arranging of racks, modules, distributed I/O (DP) racks, and interface submodules in a station window. Racks are represented by a configuration table that permits a specific number of modules to be inserted, just like a real rack.

5.2.2 Basic rule

Modules must be inserted in the rack without gaps.

Exception: For installations with one rack, one slot in the configuration table must remain free (Reserved for the interface module). With the S7-300, this is slot 3 as shown in figure 5.1.

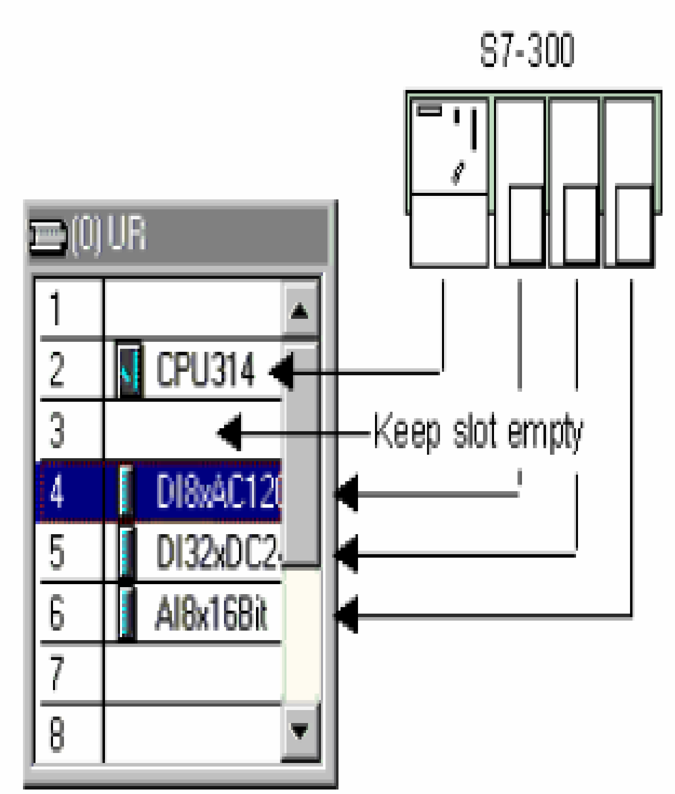


Figure 5.1 Insertion of modules in the rack

5.2.3 Slot rules (S7-300)

- Slot 1: Power supply only (for example, 6ES7 307-...) or empty.
- Slot 2: CPU only (for example, 6ES7 314-...).
- Slot 3: Interface module (for example, 6ES7 360-.../361-...) or empty.
- Slots 4 through 11: Signal or function modules, communications processors, or free.

In the previous chapter the main automatic systems have been designed, the estimated I/O required signals are as shown in table 5.1.

Table 5.1: I/O signals of systems

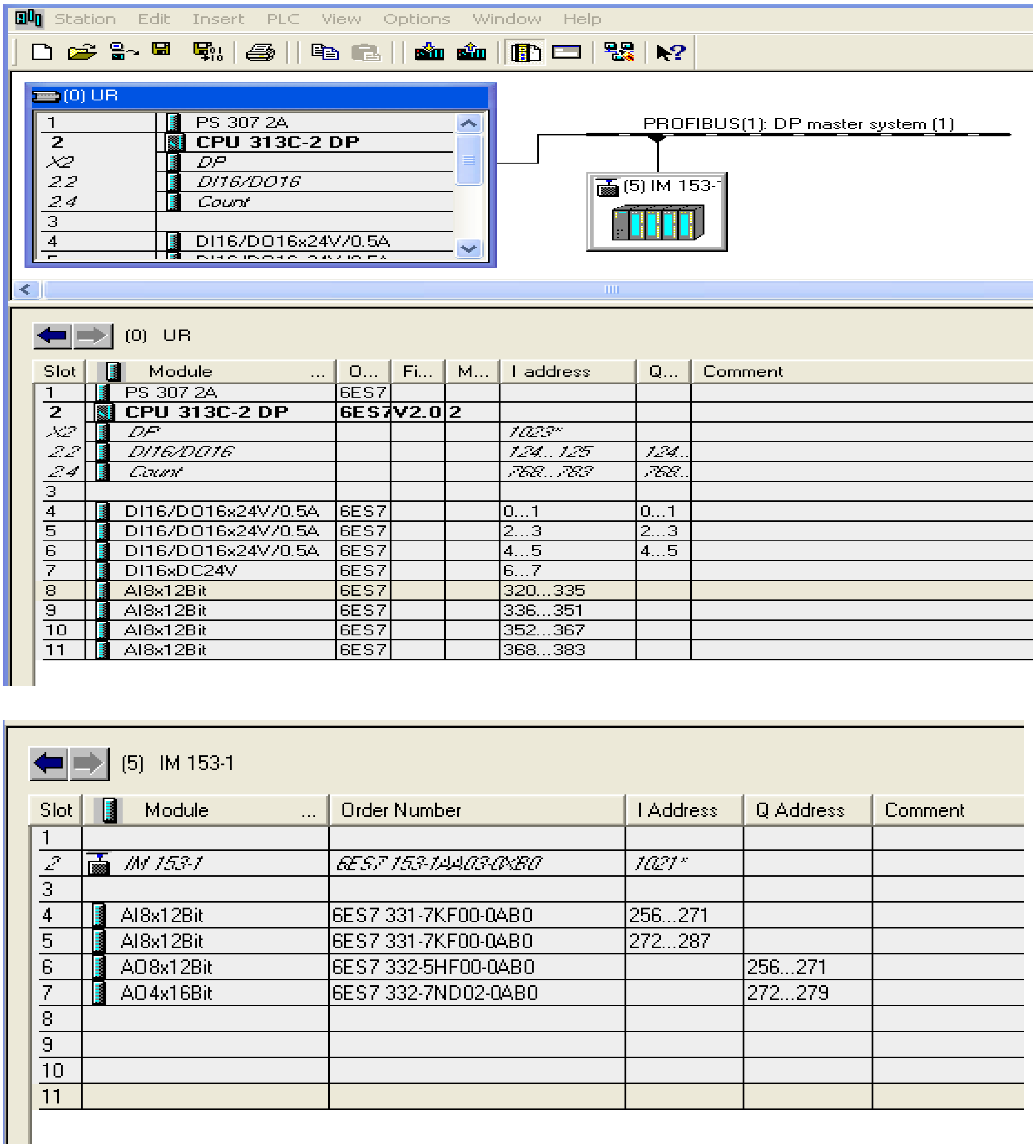
Signal type	Total number
Digital input	60
Digital output	32
Analog input	39
Analog output	8

Rack and modular PLCs is selected with components as shown in table 5.2.

Table 5.2: the Selected Modules and their Specifications

Item	Specifications	Order number	No of items
Power supply (PS 307 2A)	Load supply voltage 120/230 VAC: 24 VDC	6ES7 307-1BA00-0AA0	1
CPU 313C-2 DP	Work memory 32 KB; 0.1ms/1000 instructions; 3 pulse outputs (2.5kHz)	6ES7 313-6EC01-0AB0-/V2.0	1
DI16/DO16x24V/0.5A	Digital I/O module DI16 24 V + 16DO 24 V / 0.5 A	6ES7 323-1BL00-0AA0	3
DI16xDC24V	Digital input module DI16 24 V, grouping 16,	6ES7 321-IBH00-0AA0	1
AI8x12Bit	Analog input module AI8/12 to 14 bits.	6ES7 331-7KF00-0AB0	6
AO8x12Bit	Analog Output Module AO8/12Bit	6ES7 332-5HF00-0AB0	1
AO4x16Bit	Analog output module 4AO/16 bits	6ES7 332-7ND02-0AB0	1
DP master system	PROFIBUS(1)		1
DP SLAVE	Type IM 153-1, Family ET 200M	6ES7 153-1AA03-0XB0	1

The following figure 5.2 illustrates how these modules appear in simatic S7-300 software.



Slot	Module
1	PS 307 2A
2	**CPU 313C-2 DP**
X2	*DP*
2.2	*DI16/DO16*
2.4	*Count*
3	
4	DI16/DO16x24V/0.5A

(0) UR

Slot	Module ...	O...	Fi...	M...	I address	Q...	Comment
1	PS 307 2A	6ES7					
2	**CPU 313C-2 DP**	**6ES7**	**V2.0**	**2**			
X2	*DP*				*1023**		
2.2	*DI16/DO16*				*124...125*	*124...*	
2.4	*Count*				*768...783*	*768...*	
3							
4	DI16/DO16x24V/0.5A	6ES7			0...1	0...1	
5	DI16/DO16x24V/0.5A	6ES7			2...3	2...3	
6	DI16/DO16x24V/0.5A	6ES7			4...5	4...5	
7	DI16xDC24V	6ES7			6...7		
8	AI8x12Bit	6ES7			320...335		
9	AI8x12Bit	6ES7			336...351		
10	AI8x12Bit	6ES7			352...367		
11	AI8x12Bit	6ES7			368...383		

(5) IM 153-1

Slot	Module ...	Order Number	I Address	Q Address	Comment
1					
2	*IM 153-1*	*6ES7 153-1AA03-0XB0*	*1021**		
3					
4	AI8x12Bit	6ES7 331-7KF00-0AB0	256...271		
5	AI8x12Bit	6ES7 331-7KF00-0AB0	272...287		
6	AO8x12Bit	6ES7 332-5HF00-0AB0		256...271	
7	AO4x16Bit	6ES7 332-7ND02-0AB0		272...279	
8					
9					
10					
11					

Figure 5.2: The selected modules of the project

5.3 Program

The control program for different control tasks is written in ladder format as shown below.

5.3.1 PH Control

This program is written to maintain the PH of boiler water in the range of (9-10), by controlling the operation of caustic soda pumps (2 pumps in each phase) and solenoid valve of specific boiler. The system can be operated either automatic or manually as shown in the program below (Figure 5.3).

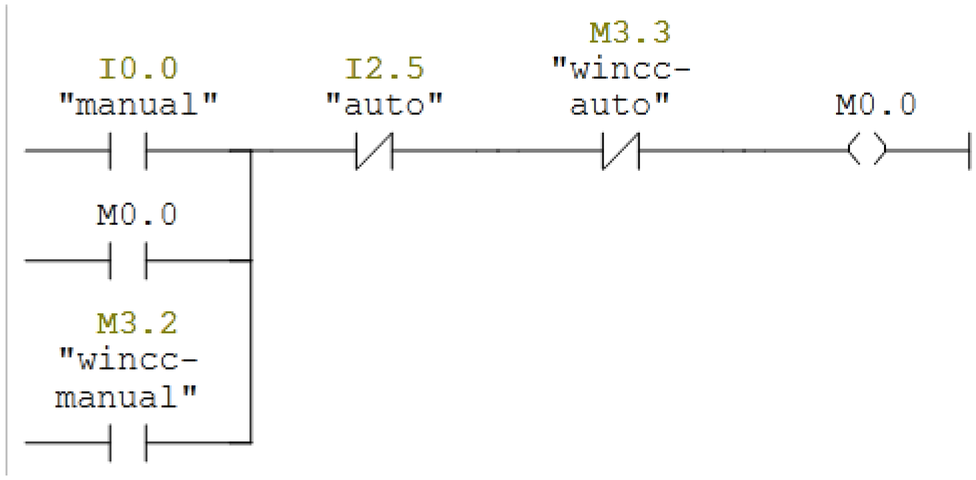


Figure 5.3: Auto / manual switching circuit

M3.2 is used to switch between the two modes by activating the memory bit m0.0, normally the system operate in auto mode, when m0.0 get energized the normal closed contact of m0.0 at network NO-2 (Figure 5.4) will open and disconnect auto loop, at the same time the normal open contact of m0.0 at network NO-3 (Figure 5.5) will close and switch the system to manual mode, in this mode all operation tasks are done by operator and not related to PH situations.

The system is designed to operate in two different mode (auto/manual), so depending on operation situation the operator can switch between them.

In auto mode the pumps and valves are operated automatically depending on PH situations, the program is shown below (figure5.4).

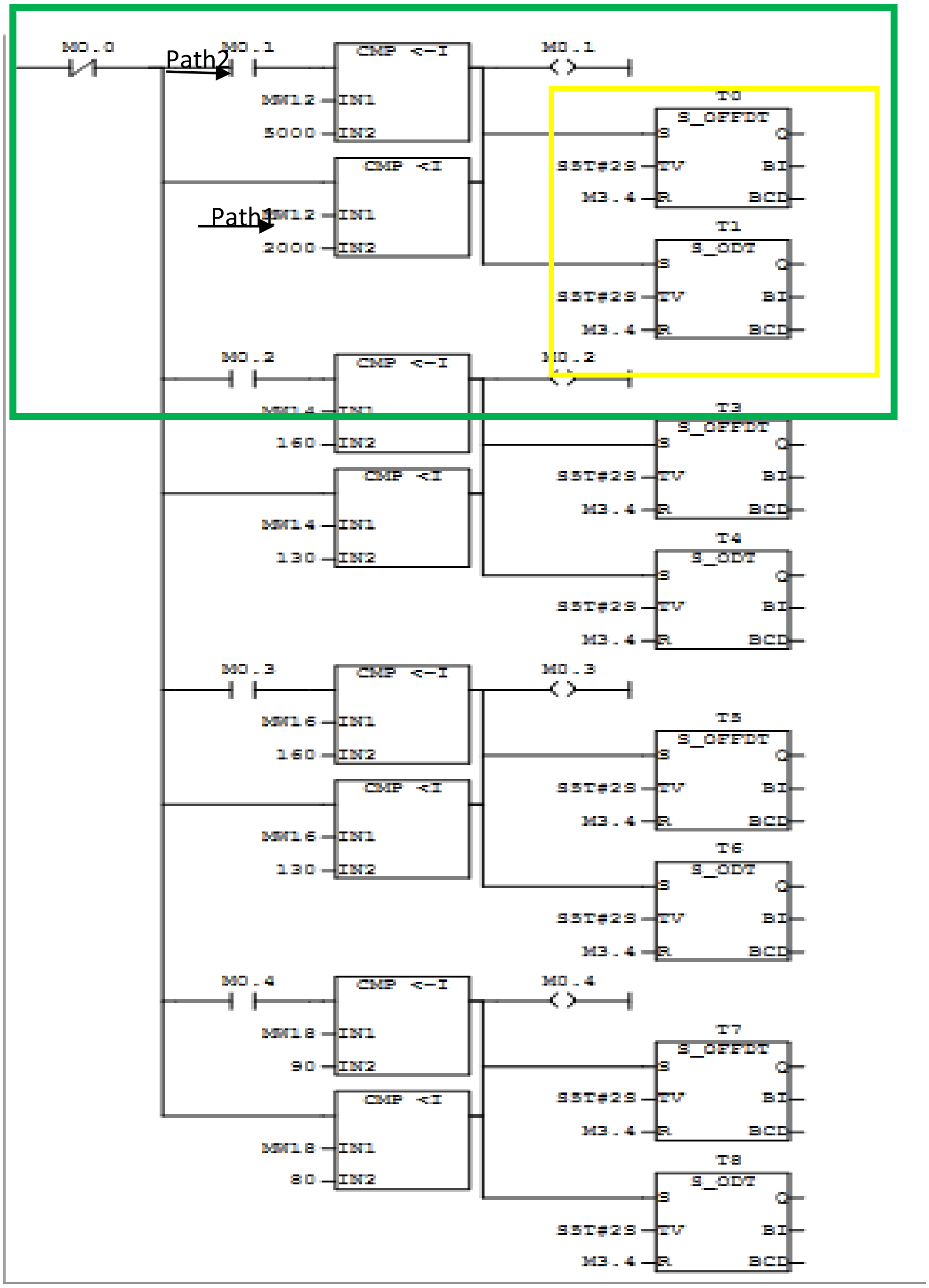


Figure 5.4: PH control loop in auto mode

The highlighted loop (green boundary) in Figure 5.4 control the PH between 9-10, the loop used two compare blocks (less than "<") and the output of them is connected to the two timers (on delay & off delay) when the PH dropped below 9 the compare blocks logic become true, and the normal opened contact of m0.1 will close, when it reached 9 the logic became false at path2 but the second path is still true , until the PH reach 10, then the output become zero and both timers will be de-energized.

The output of the T0 (off delay timer) is used to open the solenoid valve of specific boiler immediately (Figure 5.5), and after 5 seconds the caustic soda pump will be started by the second timer T1 (on delay timer) as shown in (Figure 5.6), this delay is necessary to avoid line over pressure.

In the manual mode the operation of pumps & valves is very simple, and achieved by operator only using push buttons for starting and stopping the pumps or opening and closing the valves, for example I0.3 is used to open Q0.2 (solenoid valve of boiler 2) and I1.5 to stop the same valve (Figure 5.5).

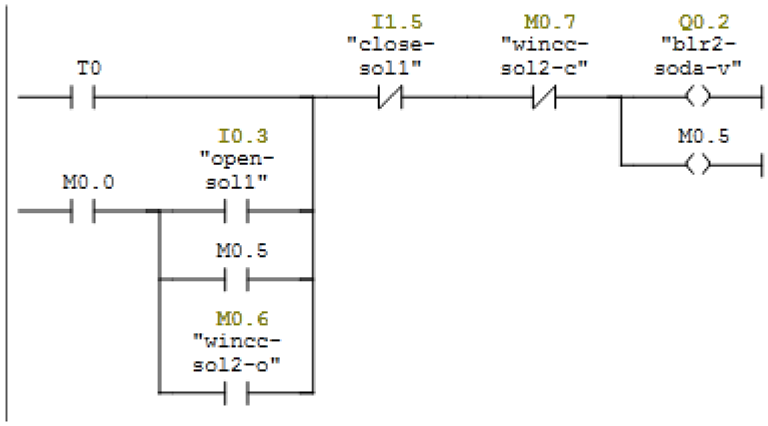


Figure 5.5: Control circuit of boiler NO-2 solenoid valve

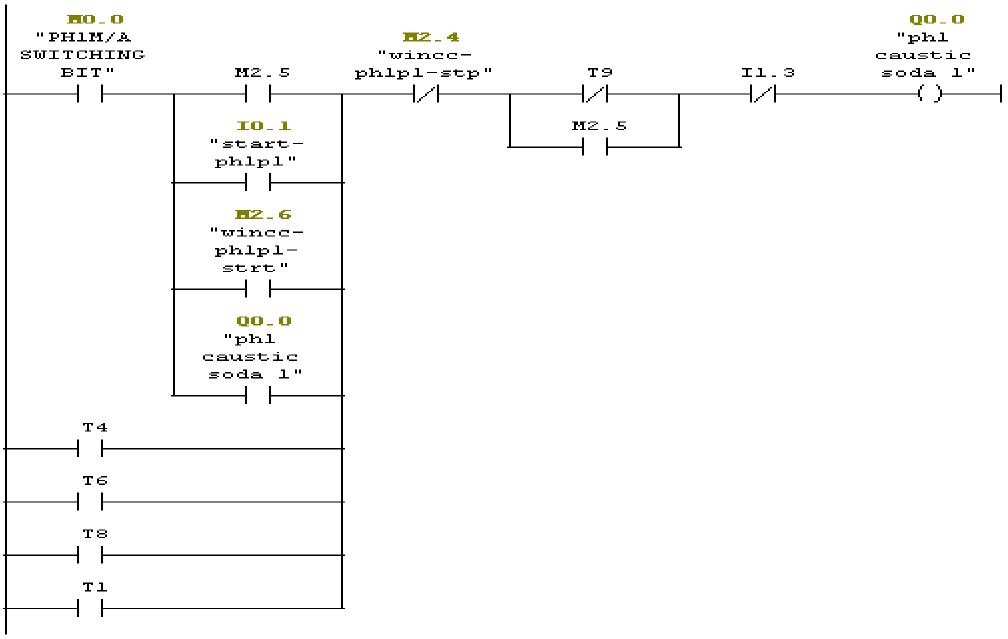


Figure 5.6: Control circuit of Ph1 caustic soda pump-1

The following figure represent wincc SCADA graphic page for the system. The system has been connected to PLC simulator and tested for both manual and auto modes in runtime, all functions have been achieved and the program is working properly.

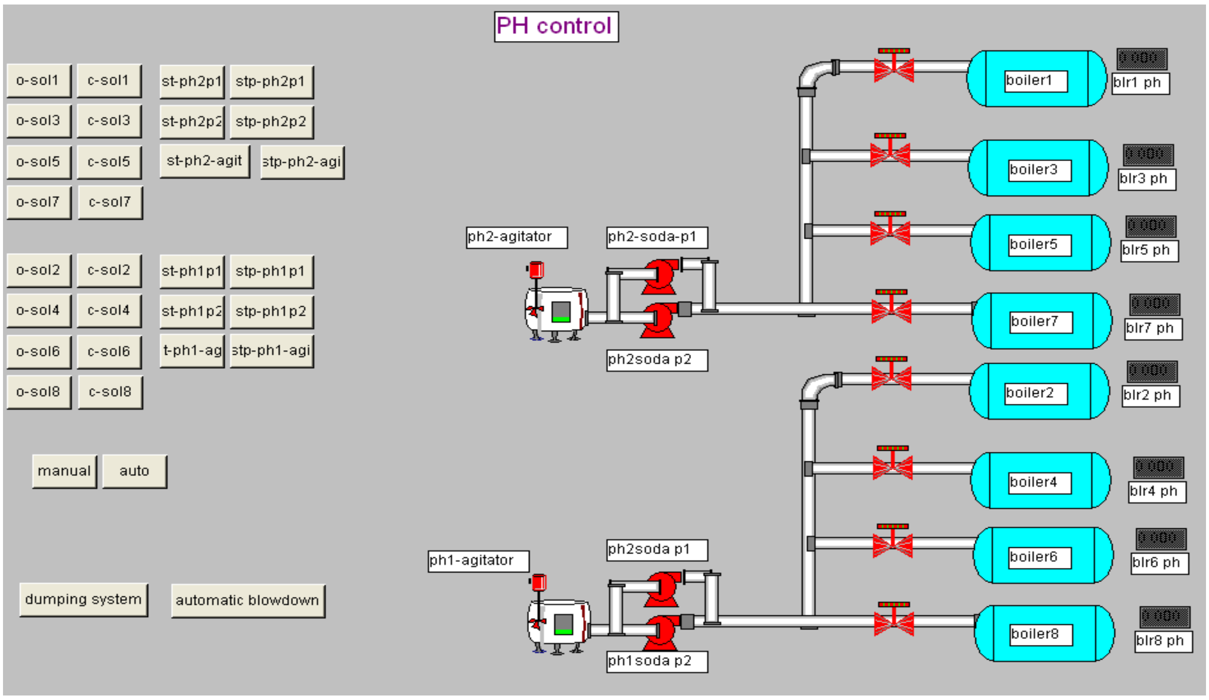


Figure 5.7: SCADA graphic page of PH control

5.3.2 Automatic dumping system control program

As mentioned in chapter four this system is designed to divert the contaminated condensate water of 1st effect evaporators to wastage water tank using 14 online conductivity sensors for individual body's. For example if the evaporator NO-1 contaminated the conductivity will rise and the block compare function result become true (mw 48 > 1000) then the three way valve (Q3.0) will be energized diverting water to sweet water tank. Figure 5.8 shows the program, only two evaporators (no-1&no-2) are represented in this figure the complete program is shown in Appendix A.

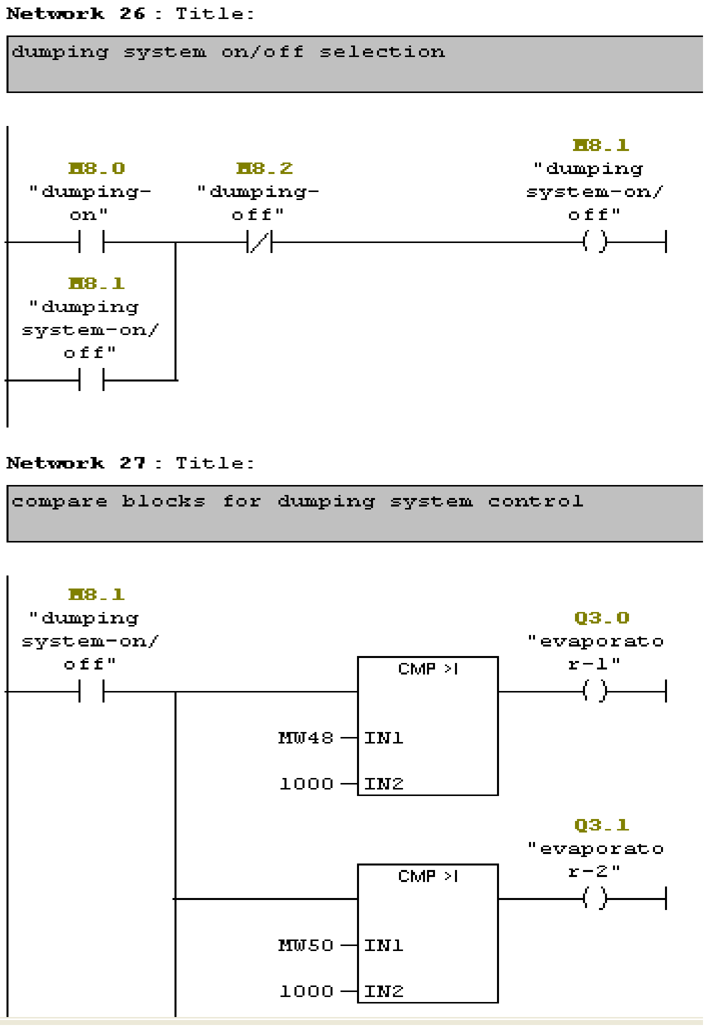


Figure 5.8: Dumping system control program

The following figure shows the SCADA graphic page of dumping system, the current screen snap shot is taken while the conductivity of evaporator no-28 is greater than 1000µs/cm which means that this body may be contaminated with sugar. It seems that the color of its diverting valves changed to green (energized), and alarm also activated to inform the operator of abnormal conditions.

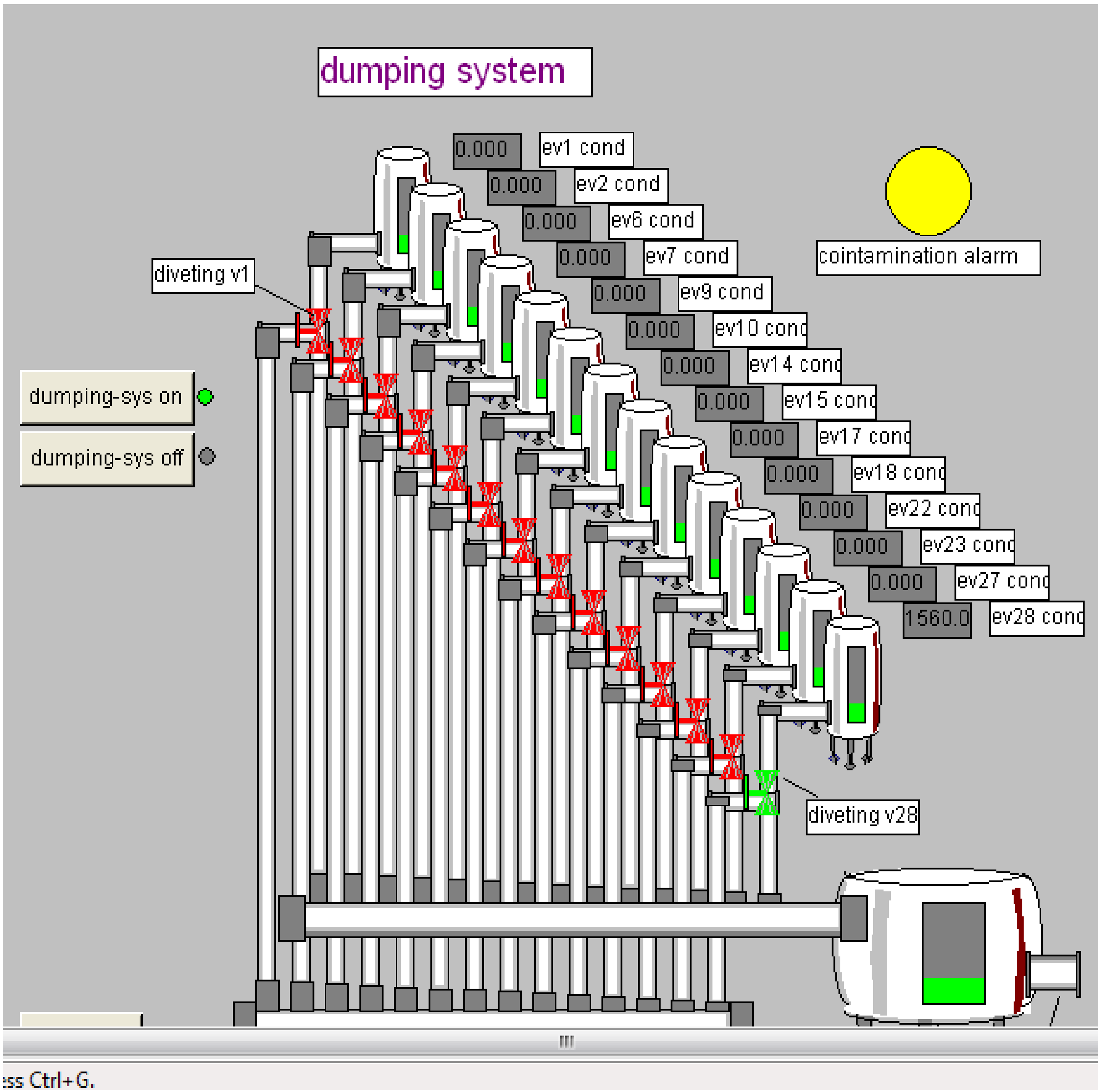


Figure 5.9: SCADA graphic page of automatic dumping system

5.3.3 Automatic blowdown program

The following Figure 5.10 shows the program of this system, the comparison logic insures that the TDS of specific boiler is maintained in the range (1200ppm-1400ppm). As shown if the drum level is normal and TDS increased for more than 1400ppm then the blowdown valve will open until the TDS drop to 1200ppm, then the valve will close and will not open again unless the TDS rise to 1400ppm. Approximately the TDS=0.7*conductivity.

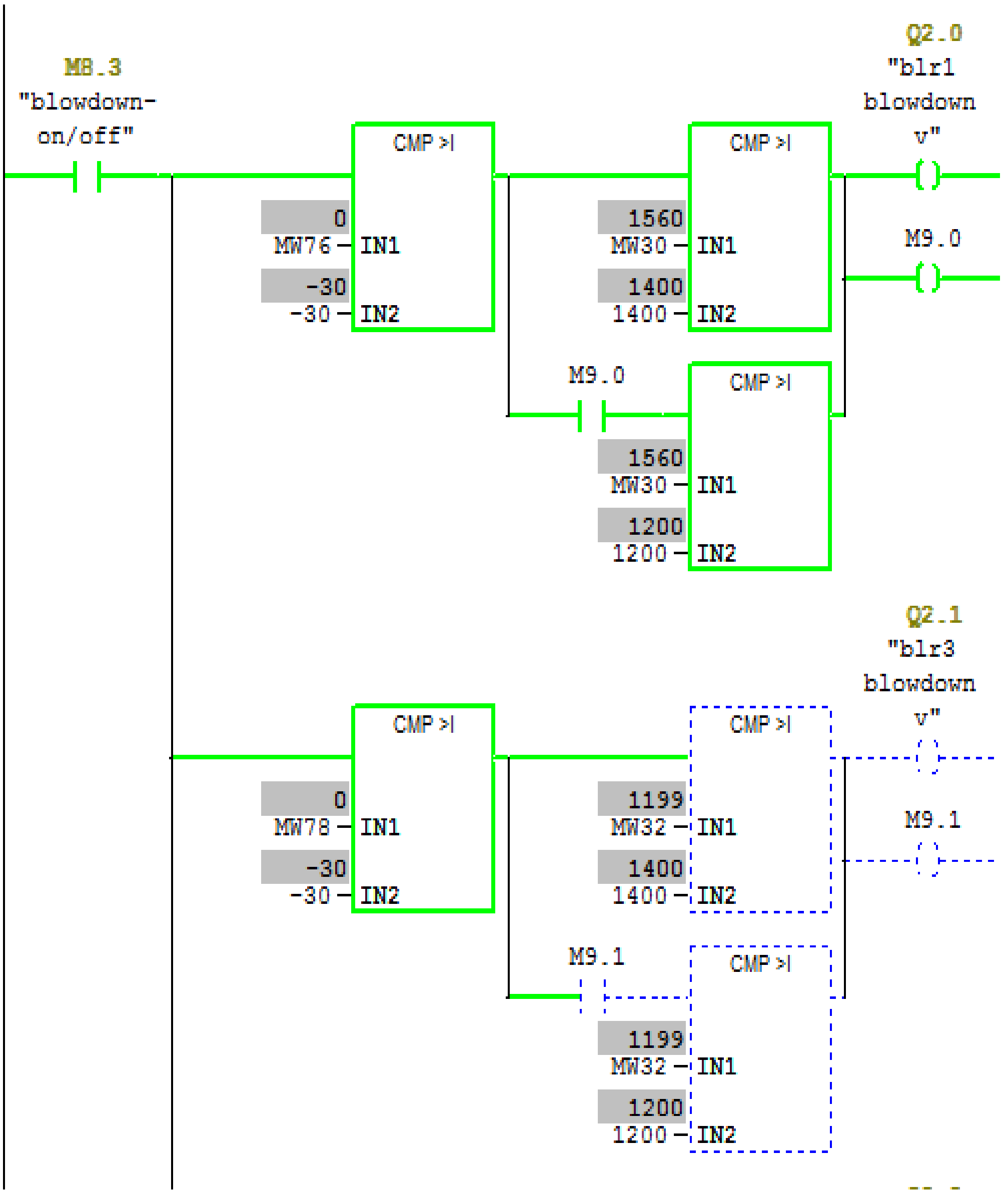


Figure 5.10: Automatic blowdown program

The SCADA graphic page of automatic blowdown system is illustrated in Figure 5.11 below.

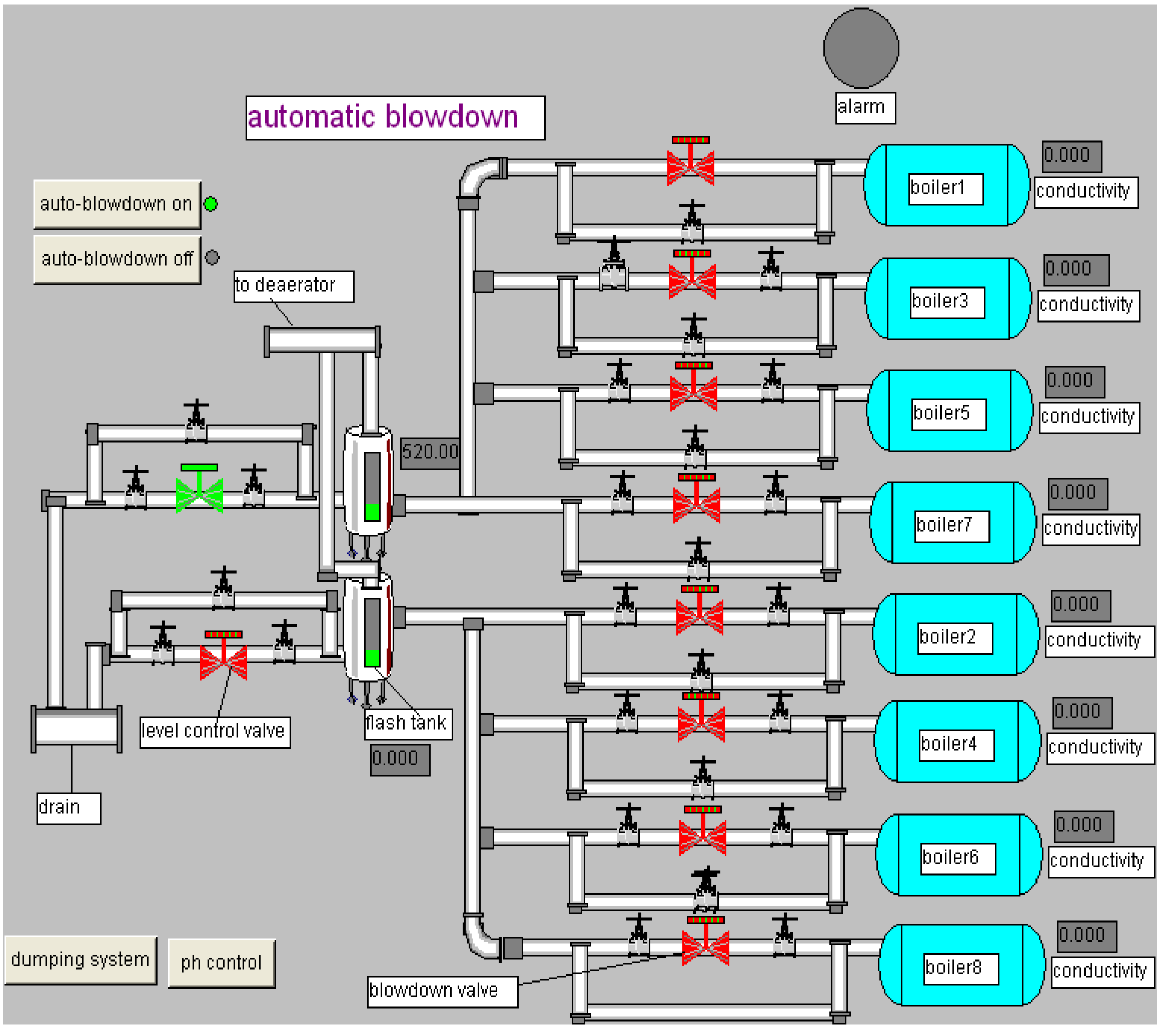


Figure 5.11 Blowdown SCADA graphic page of automatic blowdown

5.4 A brief Comparison Between Old System and New Proposed System

The following table presents some advantages of the new proposed system over the old system.

Table 5.3: Comparison between old system and new proposed system

Item	Old system	New system
Taking of samples.	Samples are taken manually and checked during specified interval time.	Samples are measured online continuously.
Chemical dosing.	Chemical dosing pumps are operated manually according to laboratory results.	Chemical dosing pumps are operated automatically through control program according to real-time state.
Blow down	Blowdown valve is opened manually by operator.	Blowdown is achieved automatically to maintain TDS at desired level
Numbers of manpower.	Depend completely on human.	Less number of operators
Chemical consumption.	Feeding of chemical is fluctuated and depends on experiences and skills of operators.	The optimum feeding of chemicals is one of the majors goals of this system.
Protection against sugar contamination incidents.	The samples are taken with interval time of 20-30 minutes so during this period the incident may occur.	Instantly the affected evaporator will be isolated alone.

CHAPTER SIX

CONCLUSION RECOMMENDATIONS

6.1 Conclusion

All the mentioned problems and issues have been considered. Sampling units were designed for eight boilers and condensate system for the purpose of online measurement of boiler feed water quality parameters such as PH and conductivity. The parameters used in monitoring system consist of conductivity and pH with 230V AC power supplies. In addition, an automatic protection devices and alarms have been included in the system to protect the analytical instruments and to inform the operator of abnormal situations. Not only does this monitoring system meet the requirements of fast response and high reliability, but also it easy of maintenance and operation. The control systems had been designed with automatic blow down, Boiler PH control, automatic dumping system insuring that the objectives of the research has been achieved.

Simatic S7 PLC has been selected with the required features and components. The control program was written in ladder format, the logics of all systems have been checked using simulator (simatic S7PLCsim), the simulation result has successfully proved that the ladder program is true and performs the objectives of different control tasks.

A dedicated WINCC SCADA HMI graphic page was created for all control systems to provide the operator with all the critical real-time information’s required for the detection and management of the plant. The system alarms have been programmed to inform the operator of any abnormal system conditions. So most critical situation such as sugar shot incidents can be avoided.

6.2 Recommendations

1. Dissolved oxygen analyzer can be used and installed at boiler water discharge header after the outlet of boiler feed water pumps to check whether the dissolved oxygen within the permissible range and using the comparison result to operate sodium sulfite (oxygen scavenger) pumps.
2. In this thesis the TDS control system has been programmed using on-off control just for simulation purpose. Real systems are recommended to be programmed using PID control to keep the level of TDS constant.
3. Alarms logging task:
   It is recommended to archive all alarms messages to inform the operator of critical situations at a very early stage and help to eliminate idle time.

REFERENCES

[1] M. J. Reid and A. Dunsmore. "*The protection of boilers from sugar contamination in feedwater*" Sugar Milling Research Institute, 1991.

[2] W. Brian Kitchen and Trae Dupre. "*Boiler treatment – facts and considerations*" Nalco Company, 3628 Hwy. 44, Garyville, LA, 2005.

[3] Kenana boiler water treatment manual, 1997.

[4] James J.Jackson, "Steam Boiler Operation" Prentice-Hall Inc,New Jersey, 1980.

[5] Tony R. Kuphaldt "Lessons In Industrial Instrumentation Version 1.0" – Released September 28, 2009.

[6] Detection of sugar beet thin juice in multiple effect evaporator condensate systems using fluorescence

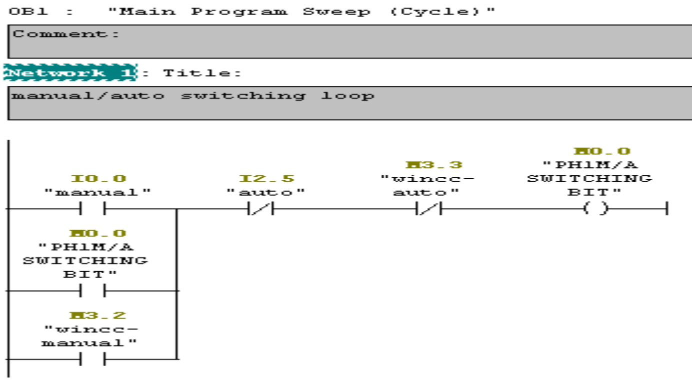
[7] Terry McGillivray, Sheldon Seaborn American Crystal Sugar 1700 N. 11th Street Moorhead, MN 5656, 1994.

[8] PH analyzer model AX460 data sheet, [Online] Available: http://www.abb.com/product/seitp330/848f20c66b51bd41c1256d2600506d6f.aspx [Accessed: 28 November 2013].

[9] Conductivity analyzer model AX411 data sheet, [Online] Available: http://www.abb.com/product/seitp330/f7cc7bdef56df734c1256d25004b1022.aspx [Accessed: 28 November 2013].

[10] Ladder Logic (LAD) for Siemens S7-300 and S7-400 Programming Reference Manual, 2010.

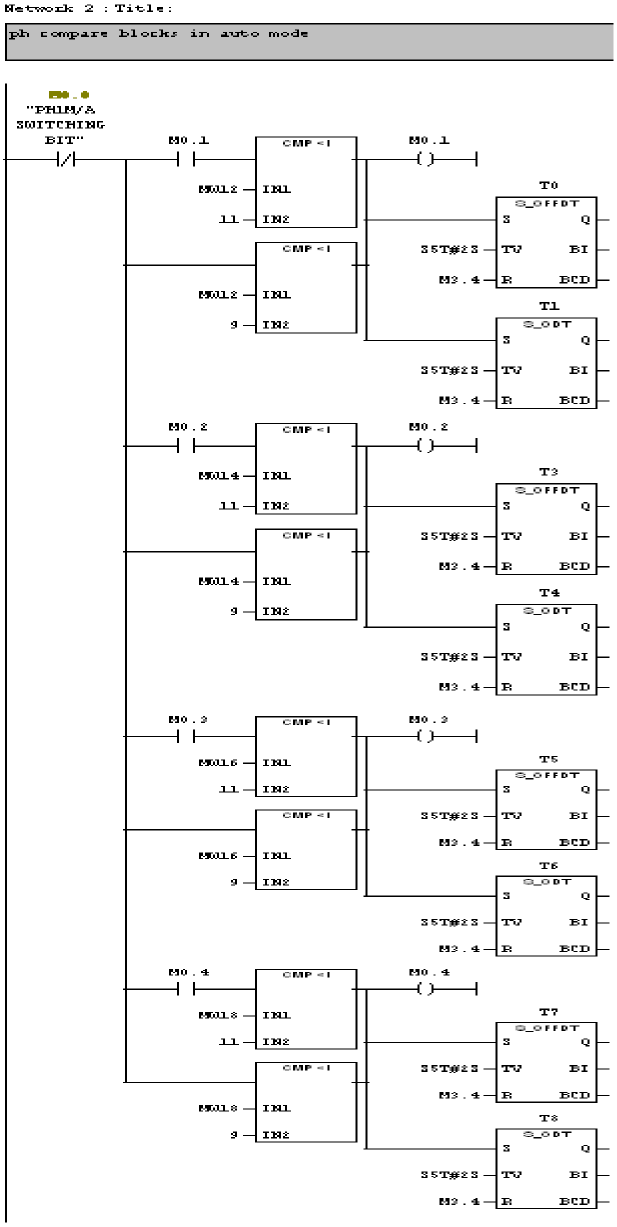
Appendix A: PLC Control Program:


OB1 : "Main Program Sweep (Cycle)"

Comment:

Network 1: Title:

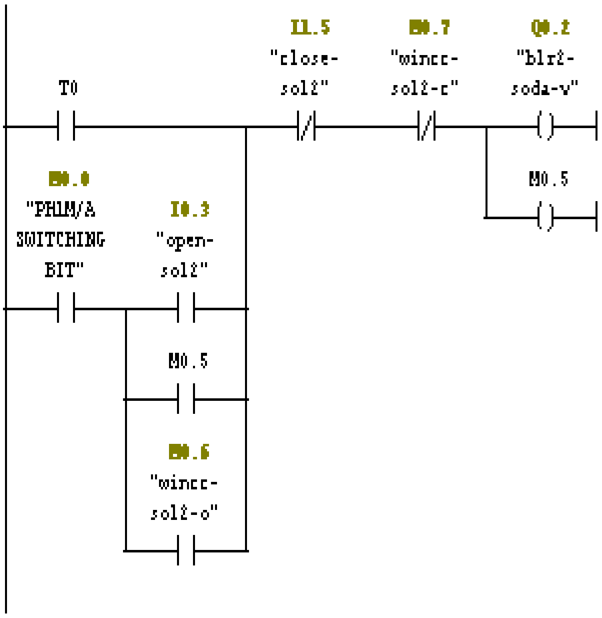
manual/auto switching loop


Network 2 : Title:

ph compare blocks in auto mode

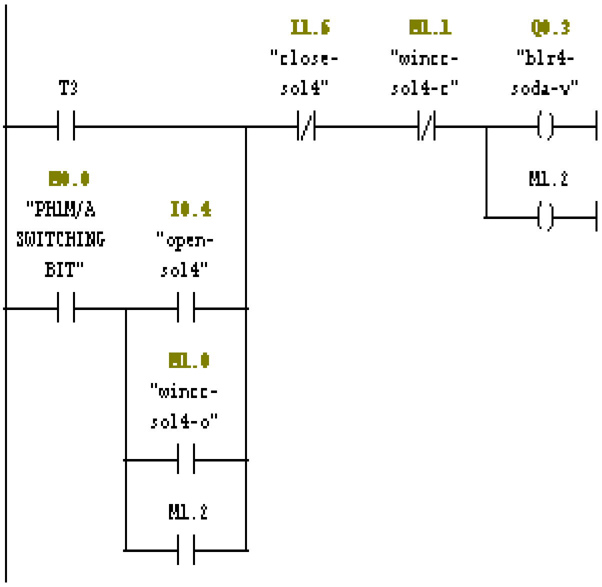
Network 3 : Title:

boiler-2 caustic soda valve control circuit



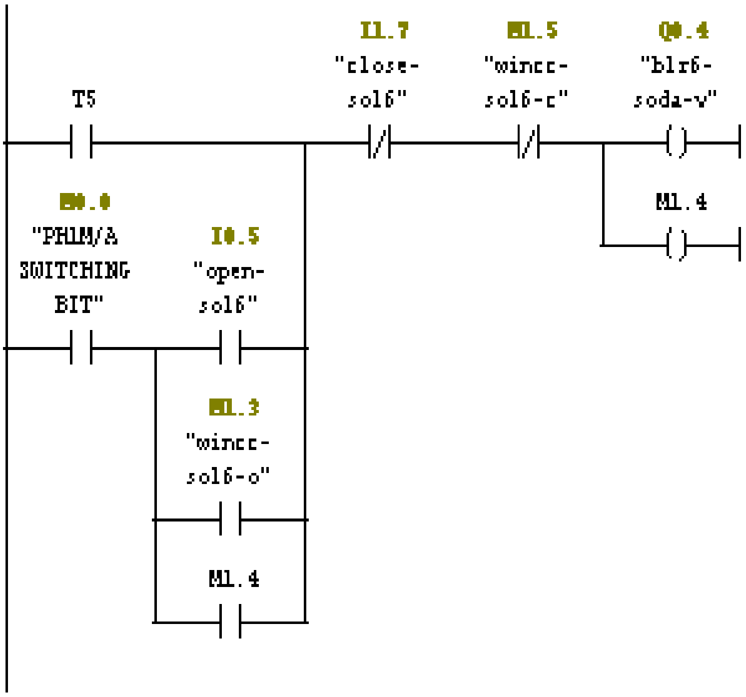
Network 4 : Title:

boiler-4 caustic soda valve control circuit



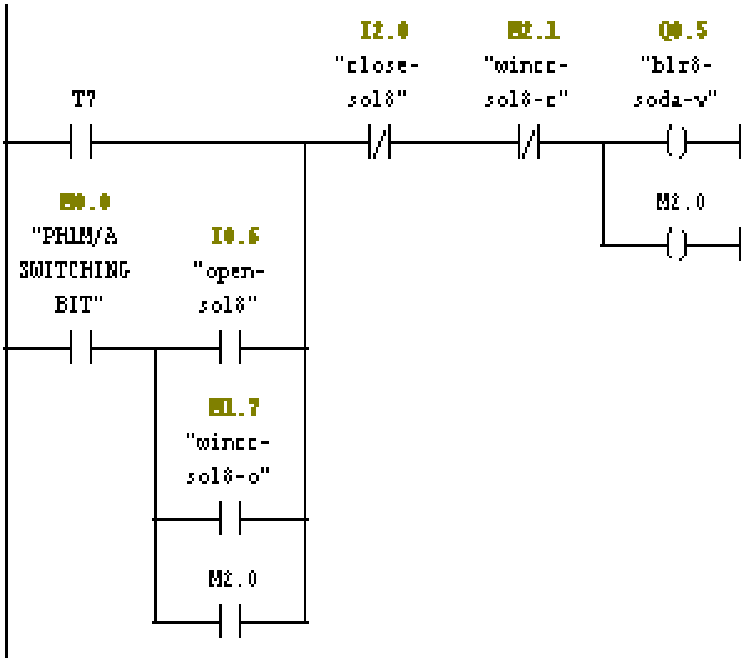
Network 5 : Title:

boiler-6 caustic soda valve control circuit



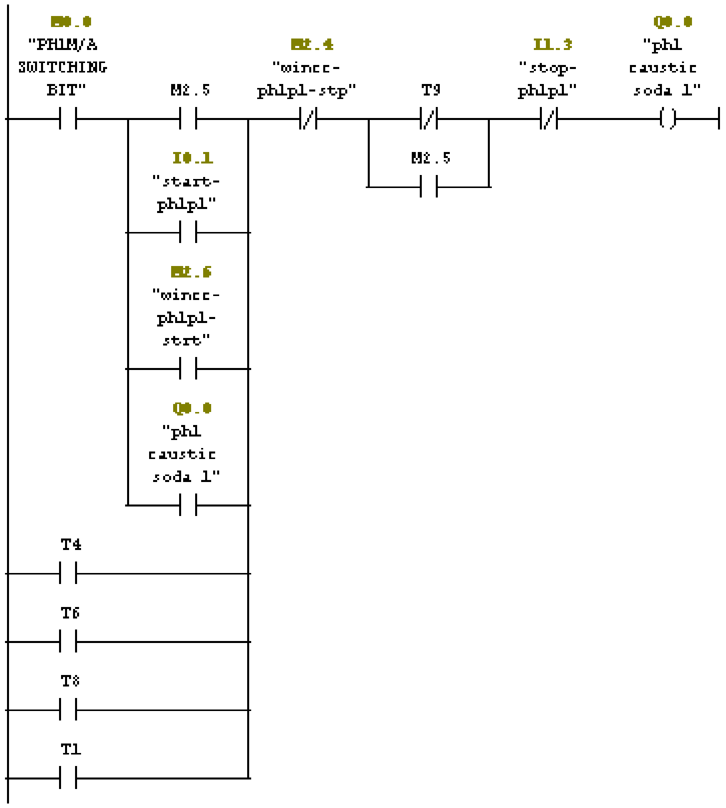
Network 6 : Title:

boiler-8 caustic soda valve control circuit



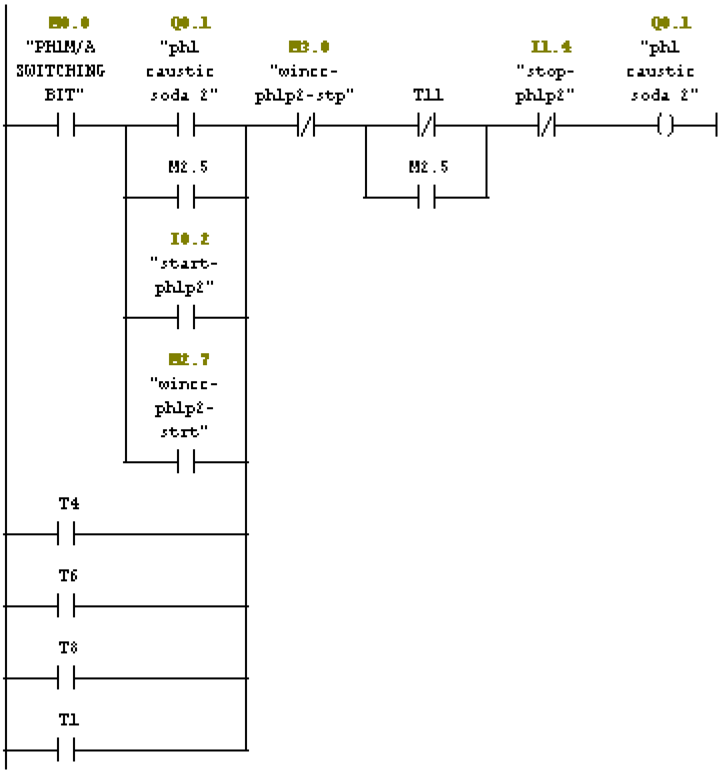
Network 7 : Title:

ph-1 caustic soda pump-1 control circuit



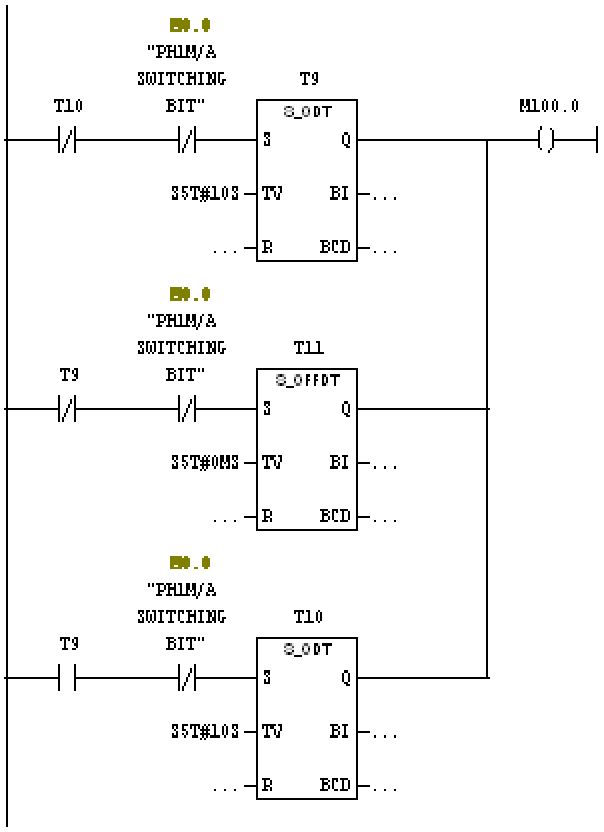
Network 8 : Title:

ph-1 caustic soda pump-2 control circuit



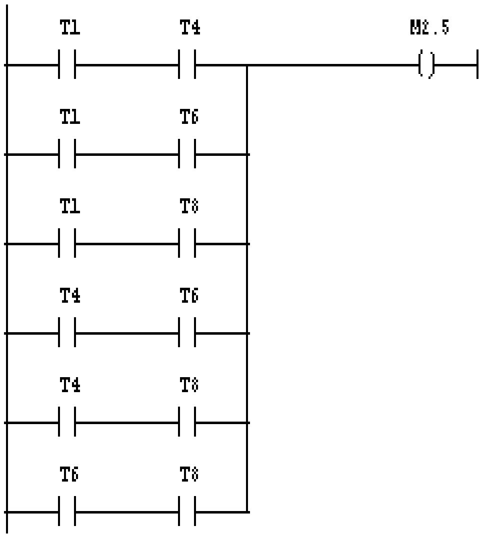
Network 9 : Title:

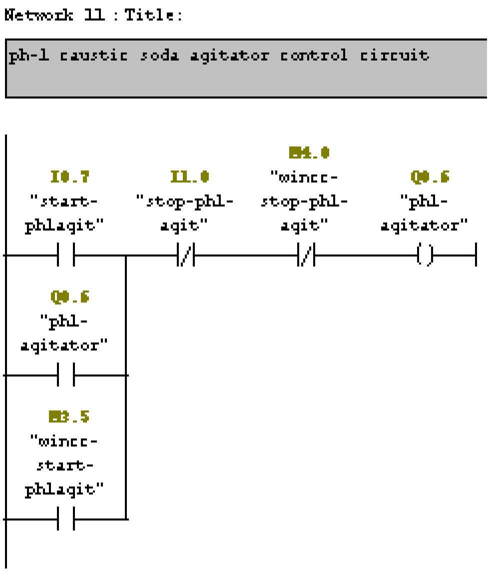
operation time control for ph-1 caustic suda pumps when the ph is dropped in only one boiler



Network 10 : Title:

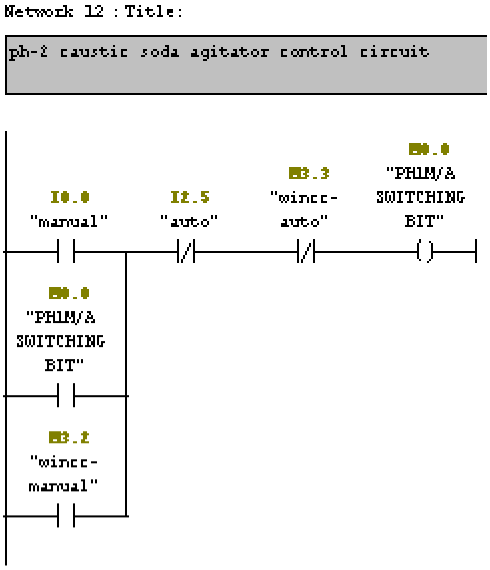
m2.5 used to put both pumps in service if the ph is dropped for more than one boiler in ph-1





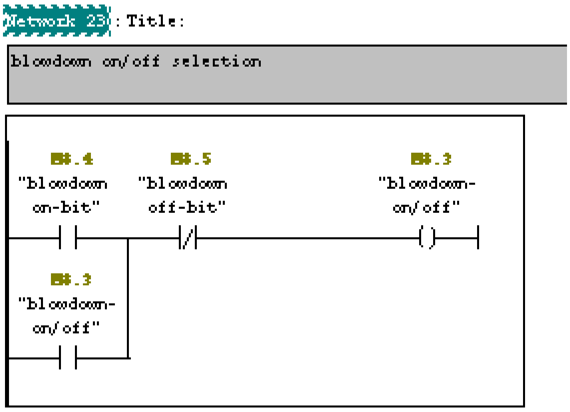
Network 11 : Title:

ph-1 caustic soda agitator control circuit



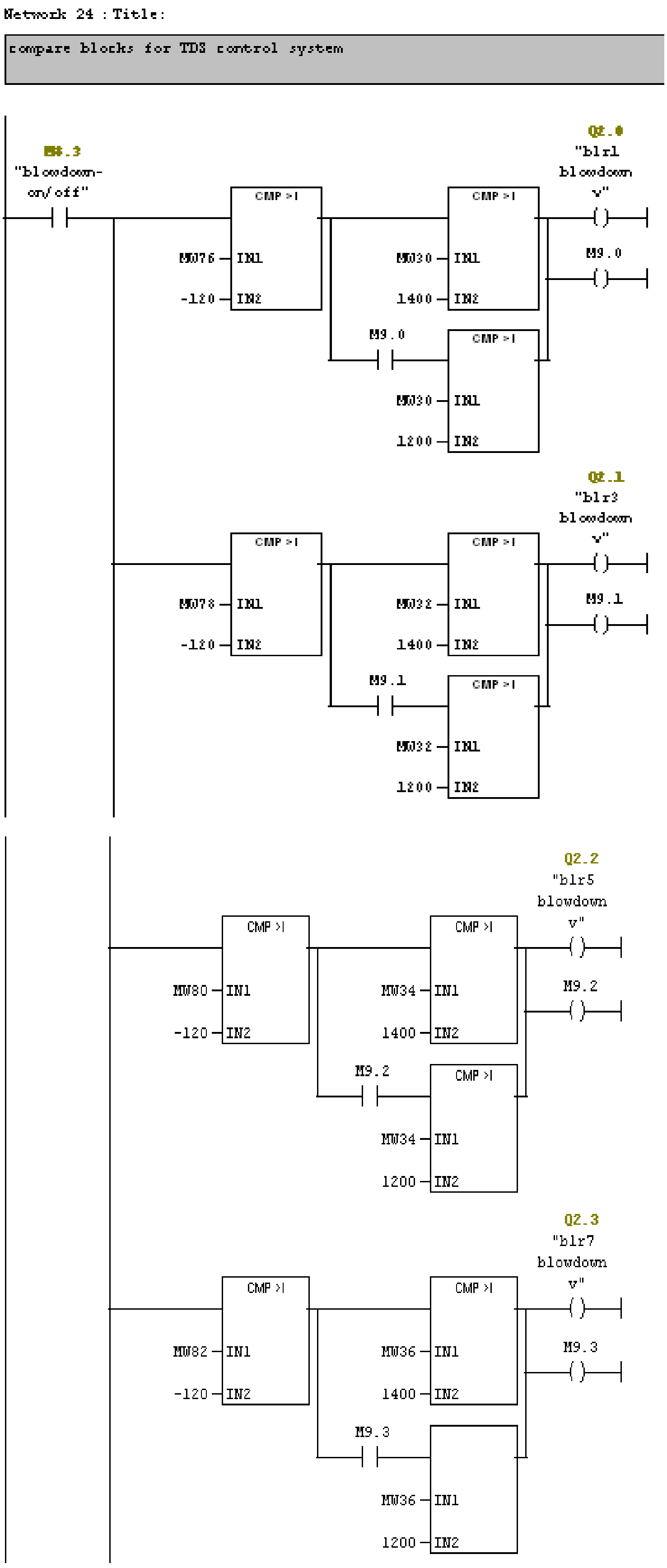
Network 12 : Title:

ph-2 caustic soda agitator control circuit



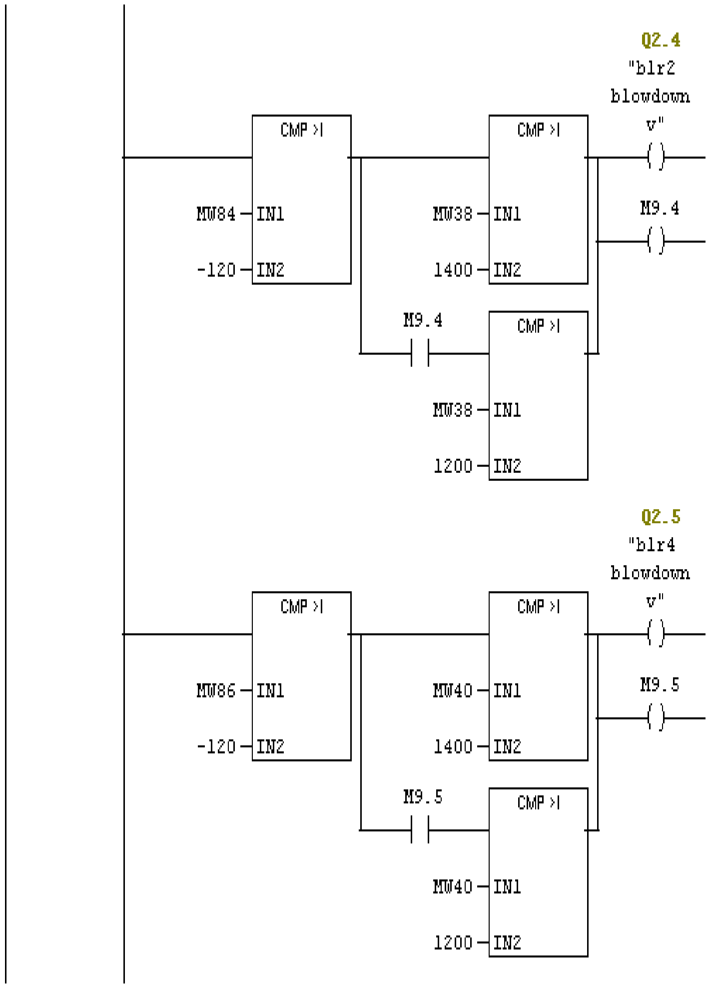
Network 23 : Title:

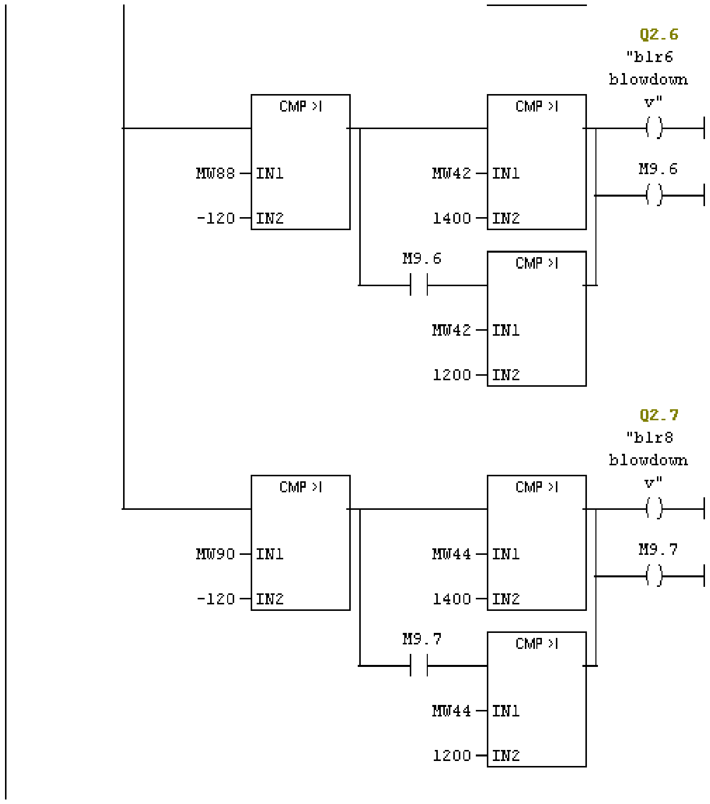
blowdown on/off selection



Network 24 : Title:

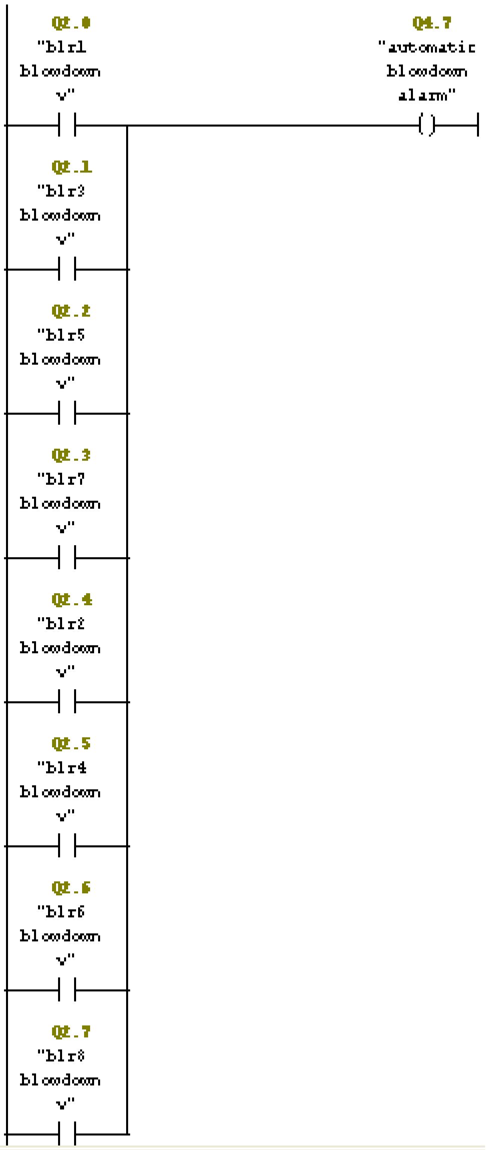
compare blocks for TDS control system


Q2.4
"blr2 blowdown v"
CMP >I
MW84
IN1
-120
IN2
CMP >I
MW38
IN1
1400
IN2
M9.4
M9.4
CMP >I
MW38
IN1
1200
IN2
Q2.5
"blr4 blowdown v"
CMP >I
MW86
IN1
-120
IN2
CMP >I
MW40
IN1
1400
IN2
M9.5
M9.5
CMP >I
MW40
IN1
1200
IN2


Q2.6
"blr6 blowdown v"
CMP >I
MW88
IN1
-120
IN2
CMP >I
MW42
IN1
1400
IN2
M9.6
M9.6
CMP >I
MW42
IN1
1200
IN2
Q2.7
"blr8 blowdown v"
CMP >I
MW90
IN1
-120
IN2
CMP >I
MW44
IN1
1400
IN2
M9.7
M9.7
CMP >I
MW44
IN1
1200
IN2

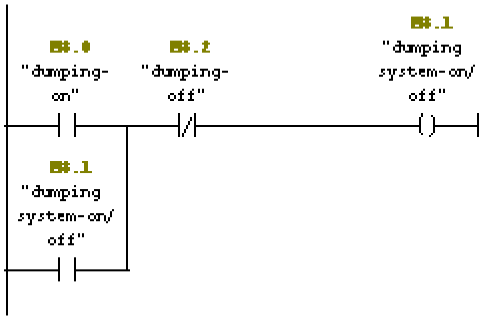
Network 25 : Title:

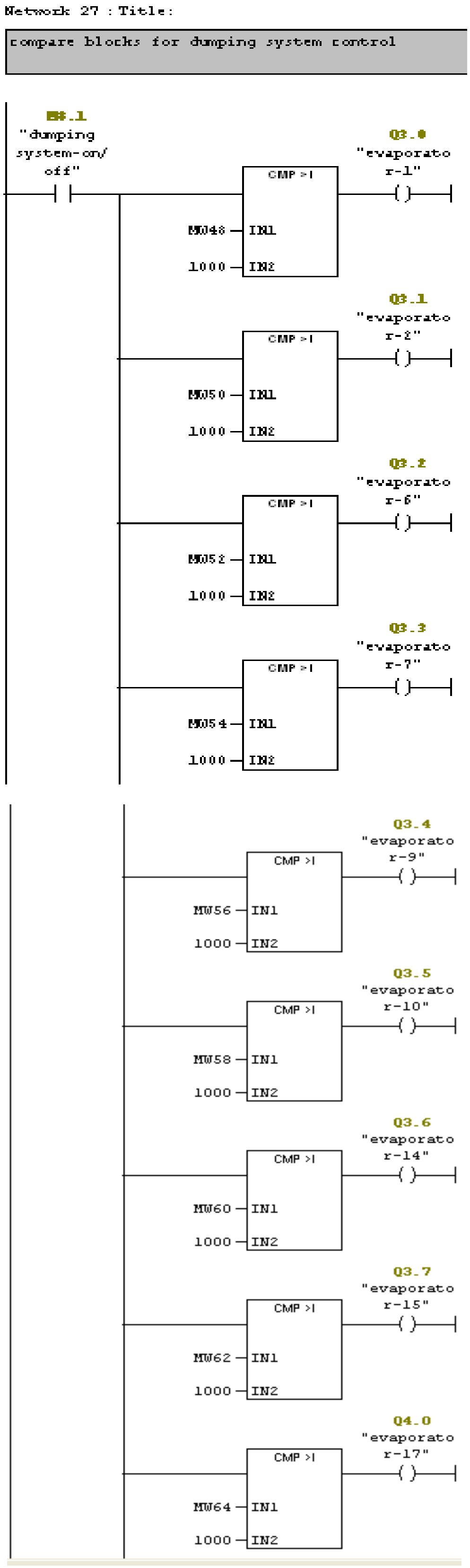
blowdown alarm logic



Network 26 : Title:

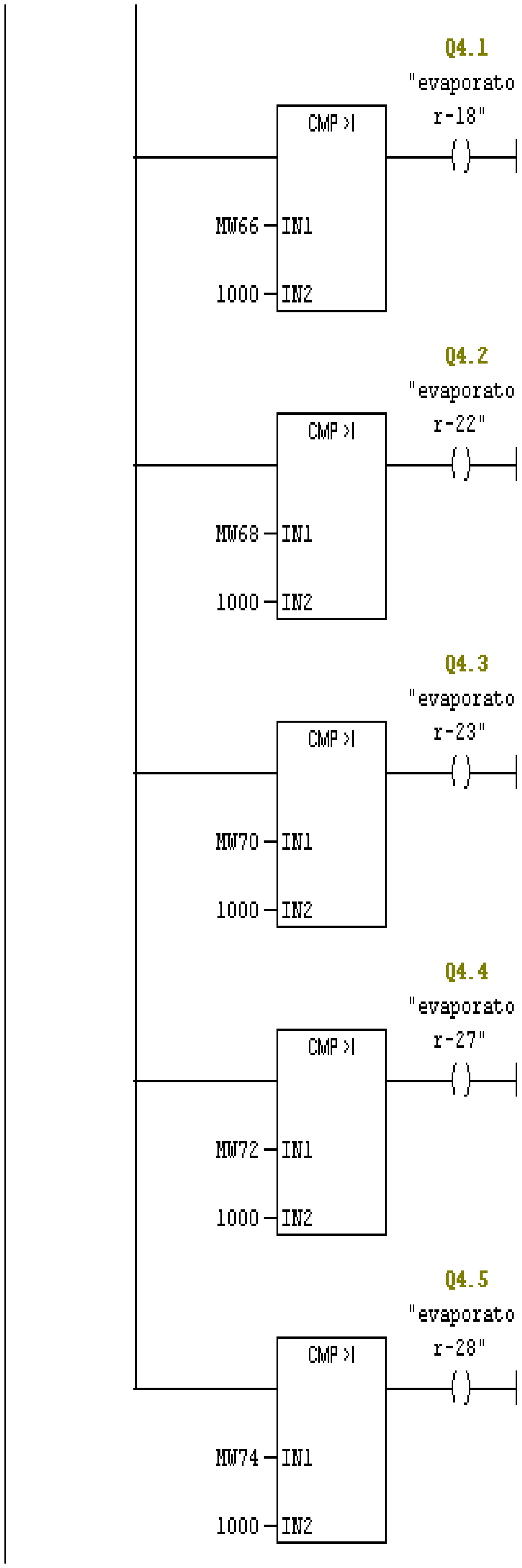
dumping system on/off selection





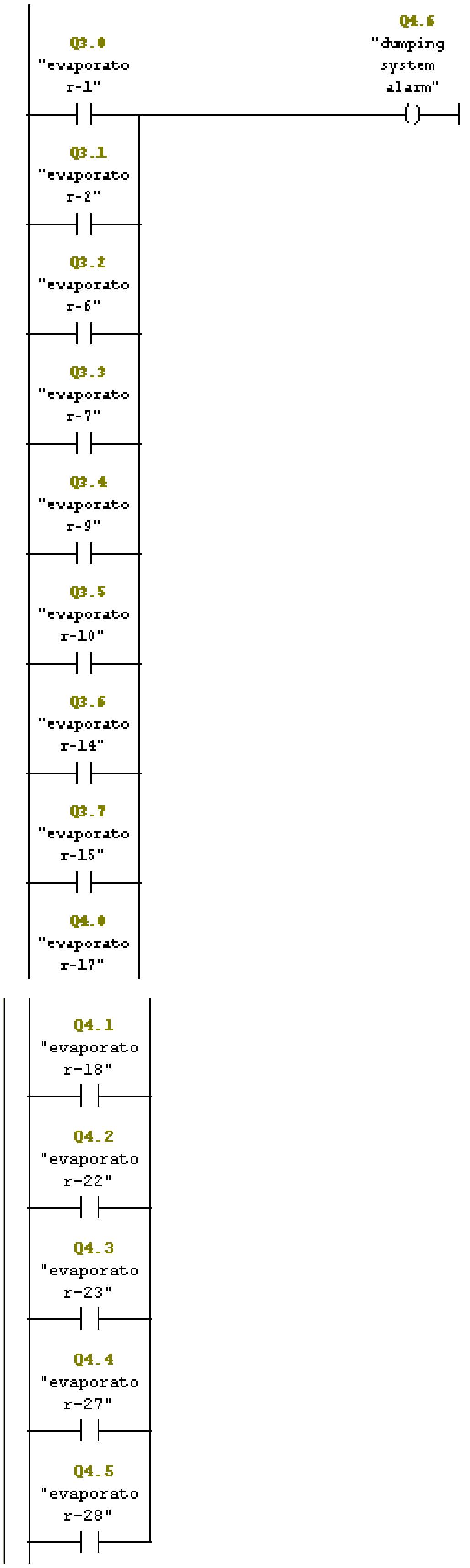
Network 27 : Title:

compare blocks for dumping system control


Q4.1
"evaporator-18"
CMP >I
MW66
IN1
1000
IN2
Q4.2
"evaporator-22"
CMP >I
MW68
IN1
1000
IN2
Q4.3
"evaporator-23"
CMP >I
MW70
IN1
1000
IN2
Q4.4
"evaporator-27"
CMP >I
MW72
IN1
1000
IN2
Q4.5
"evaporator-28"
CMP >I
MW74
IN1
1000
IN2

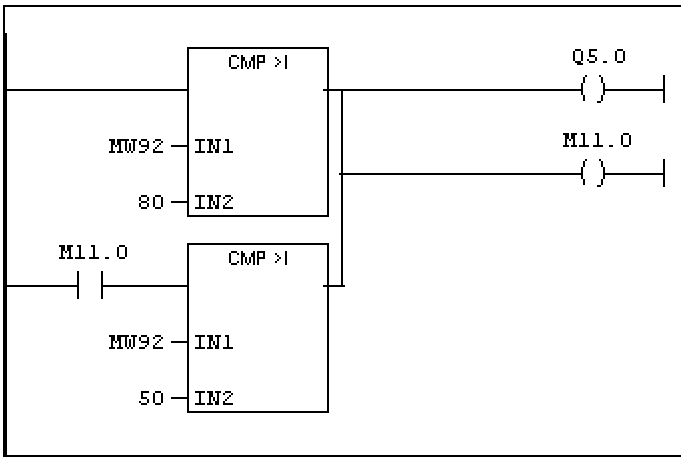
Network 28 : Title:

alarm logic for dumping system



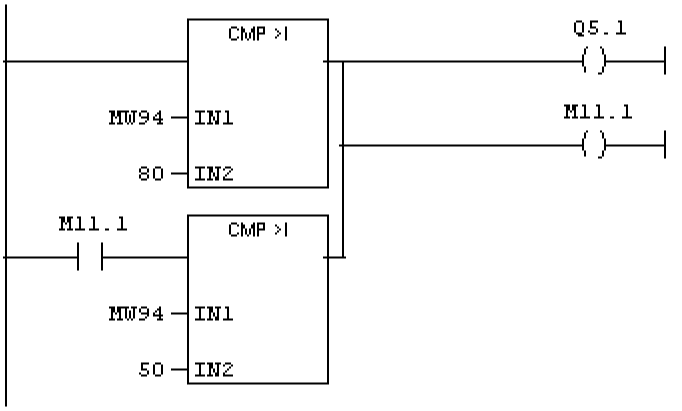
Network 29 : Title:

ph1 flash tank



Network 30 : Title:

ph2 flash tank



Appendix B: Addresses of I/O Units and Internal Memory

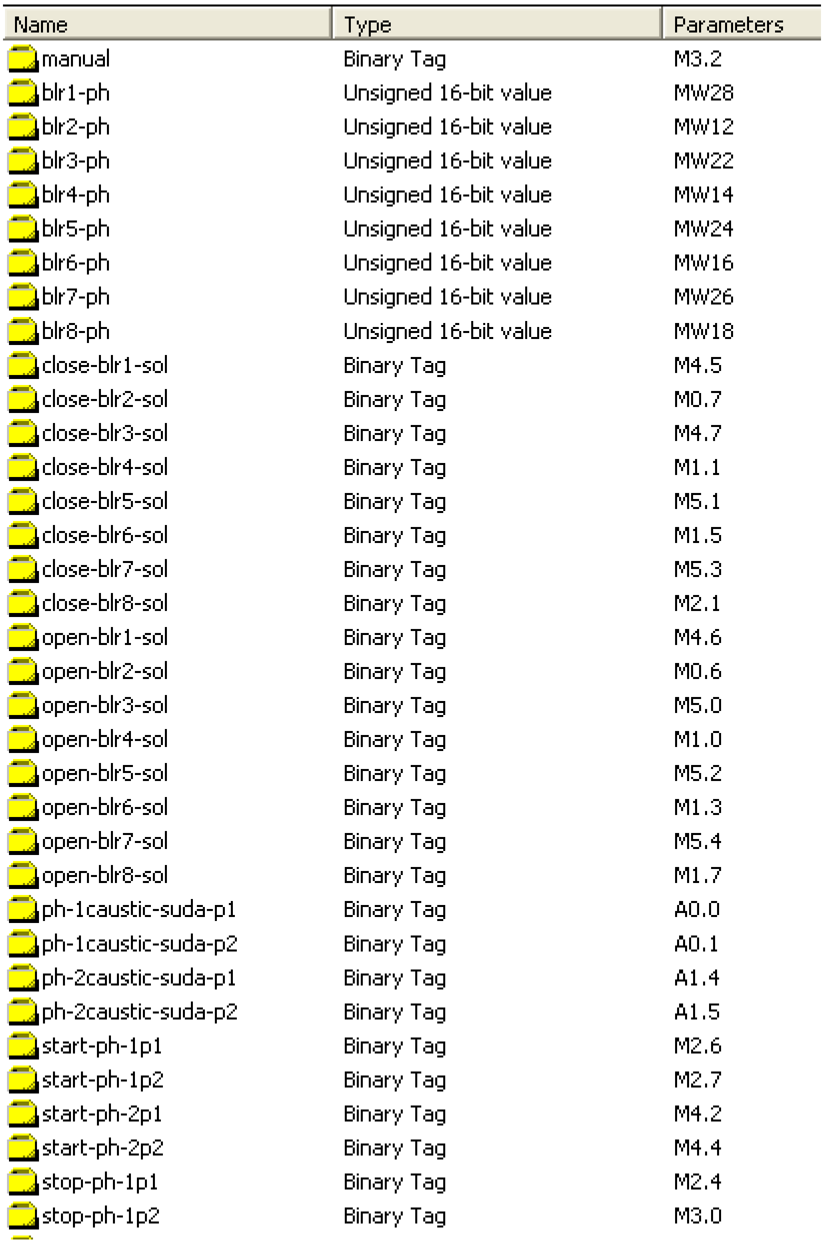
Symbol	Address	Data type
Auto	I 2.5	BOOL
automatic blowdown alarm	Q 4.7	BOOL
blowdown-on/off	M 8.3	BOOL
blowdown off-bit	M 8.5	BOOL
blowdown on-bit	M 8.4	BOOL
blr1-soda-v	Q 1.0	BOOL
blr1 blowdown v	Q 2.0	BOOL
blr2-soda-v	Q 0.2	BOOL
blr2 blowdown v	Q 2.4	BOOL
blr3-soda-v	Q 1.1	BOOL
blr3 blowdown v	Q 2.1	BOOL
blr4-soda-v	Q 0.3	BOOL
blr4 blowdown v	Q 2.5	BOOL
blr5-soda-v	Q 1.2	BOOL
blr5 blowdown v	Q 2.2	BOOL
blr6-soda-v	Q 0.4	BOOL
blr6 blowdown v	Q 2.6	BOOL
blr7-soda-v	Q 1.3	BOOL
blr7 blowdown v	Q 2.3	BOOL
blr8-soda-v	Q 0.5	BOOL
blr8 blowdown v	Q 2.7	BOOL
close-sol1	I 2.6	BOOL
close-sol2	I 1.5	BOOL
close-sol3	I 2.7	BOOL
close-sol4	I 1.6	BOOL
close-sol5	I 3.0	BOOL
close-sol6	I 1.7	BOOL
close-sol7	I 3.1	BOOL
close-sol8	I 2.0	BOOL
Cycle Execution	OB 1	OB 1
dumping-off	M 8.2	BOOL
dumping-on	M 8.0	BOOL
dumping system-on/off	M 8.1	BOOL

dumping system alarm	Q 4.6	BOOL
evaporator-1	Q 3.0	BOOL
evaporator-10	Q 3.5	BOOL
evaporator-14	Q 3.6	BOOL
evaporator-15	Q 3.7	BOOL
evaporator-17	Q 4.0	BOOL
evaporator-18	Q 4.1	BOOL
evaporator-2	Q 3.1	BOOL
evaporator-22	Q 4.2	BOOL
evaporator-23	Q 4.3	BOOL
evaporator-27	Q 4.4	BOOL
evaporator-28	Q 4.5	BOOL
evaporator-6	Q 3.2	BOOL
evaporator-7	Q 3.3	BOOL
evaporator-9	Q 3.4	BOOL
manual	I 0.0	BOOL
open-sol1	I 2.1	BOOL
open-sol2	I 0.3	BOOL
open-sol3	I 2.2	BOOL
open-sol4	I 0.4	BOOL
open-sol5	I 2.3	BOOL
open-sol6	I 0.5	BOOL
open-sol7	I 2.4	BOOL
open-sol8	I 0.6	BOOL
ph1-aqitator	Q 0.6	BOOL
ph1 caustic soda 1	Q 0.0	BOOL
ph1 caustic soda 2	Q 0.1	BOOL
ph1 flash tank level	MW 92	WORD
PH1M/A SWITCHING BIT	M 0.0	BOOL
ph2-aqitator	Q 0.7	BOOL
ph2 caustic soda 1	Q 1.4	BOOL
ph2 caustic soda 2	Q 1.5	BOOL
ph2 flash tank level	MW 94	WORD
start-ph1aqit	I 0.7	BOOL
start-ph1p1	I 0.1	BOOL

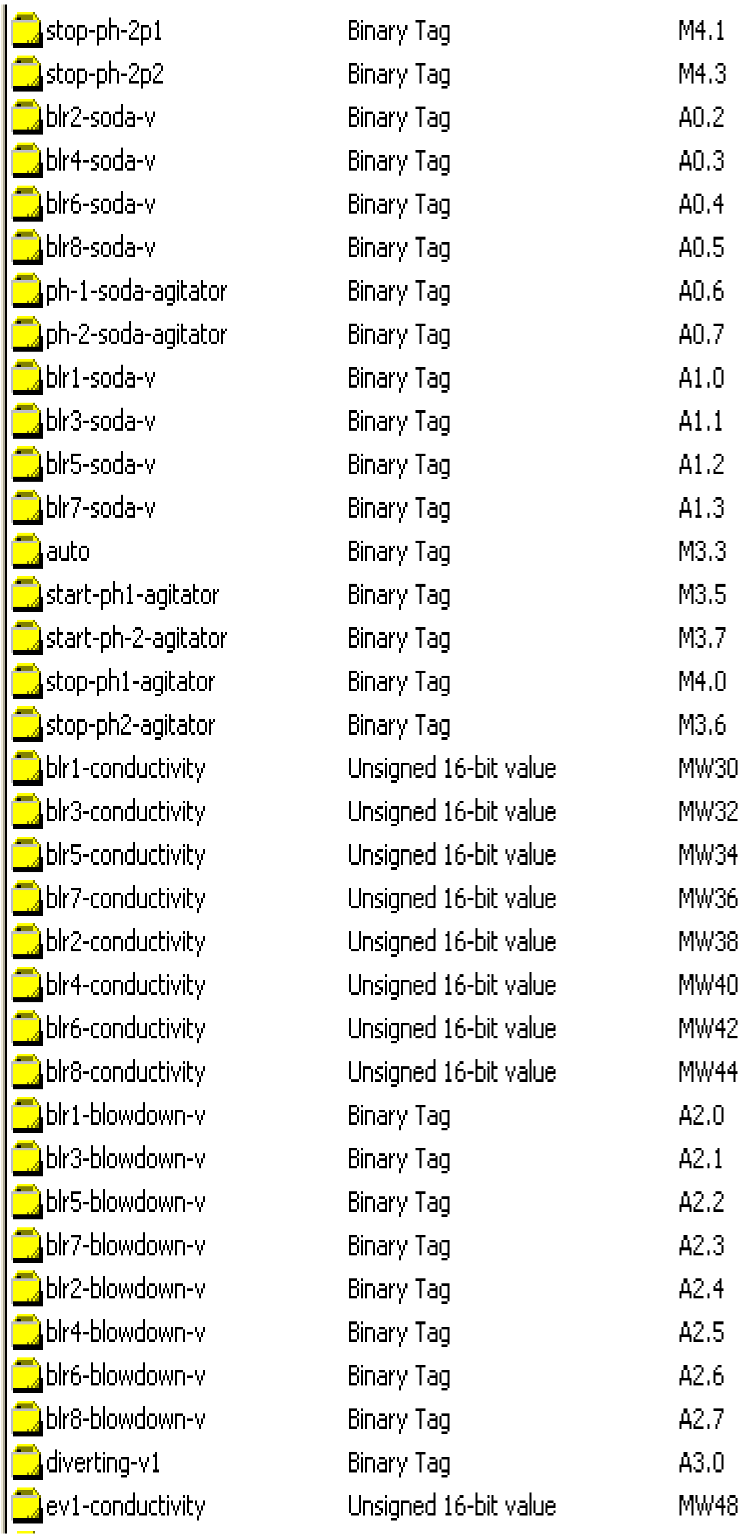
start-ph1p2	I 0.2	BOOL
start-ph2aqit	I 1.1	BOOL
start-ph2p1	I 3.2	BOOL
start-ph2p2	I 3.3	BOOL
stop-ph1-aqit	I 1.0	BOOL
stop-ph1p1	I 1.3	BOOL
stop-ph1p2	I 1.4	BOOL
stop-ph2-aqit	I 1.2	BOOL
stop-ph2p1	I 3.5	BOOL
stop-ph2p2	I 3.4	BOOL
wincc-auto	M 3.3	BOOL
wincc-manual	M 3.2	BOOL
wincc-ph1p1-stp	M 2.4	BOOL
wincc-ph1p1-strt	M 2.6	BOOL
wincc-ph1p2-stp	M 3.0	BOOL
wincc-ph1p2-strt	M 2.7	BOOL
wincc-ph2p1-stp	M 4.1	BOOL
wincc-ph2p1-strt	M 4.2	BOOL
wincc-ph2p2-stp	M 4.3	BOOL
wincc-ph2p2-strt	M 4.4	BOOL
wincc-sol1-c	M 4.5	BOOL
wincc-sol1-o	M 4.6	BOOL
wincc-sol2-c	M 0.7	BOOL
wincc-sol2-o	M 0.6	BOOL
wincc-sol3-c	M 4.7	BOOL
wincc-sol3-o	M 5.0	BOOL
wincc-sol4-c	M 1.1	BOOL
wincc-sol4-o	M 1.0	BOOL
wincc-sol5-c	M 5.1	BOOL
wincc-sol5-o	M 5.2	BOOL
wincc-sol6-c	M 1.5	BOOL
wincc-sol6-o	M 1.3	BOOL
wincc-sol7-c	M 5.3	BOOL
wincc-sol7-o	M 5.4	BOOL
wincc-sol8-c	M 2.1	BOOL

wincc-sol8-o	M	1.7	BOOL
wincc-start-ph1aqit	M	3.5	BOOL
wincc-start-ph2aqit	M	3.7	BOOL
wincc-stop-ph1-aqit	M	4.0	BOOL
wincc-stop-ph2-aqit	M	3.6	BOOL

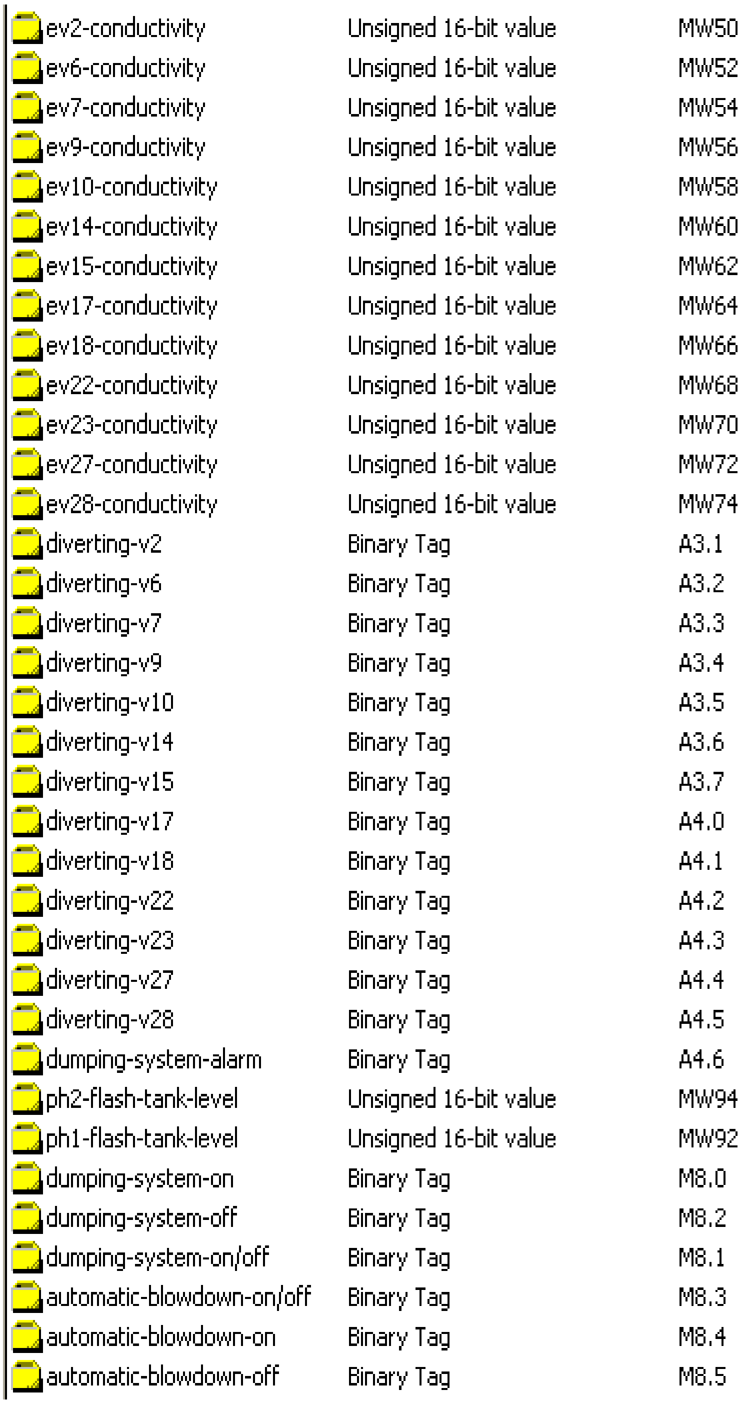
Appendix C: SCADA Tags Names:



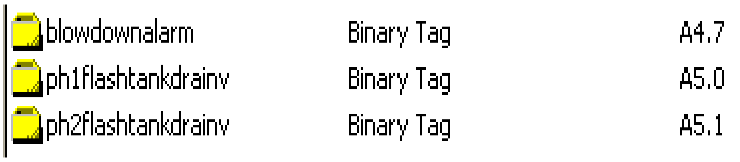
Name	Type	Parameters
manual	Binary Tag	M3.2
blr1-ph	Unsigned 16-bit value	MW28
blr2-ph	Unsigned 16-bit value	MW12
blr3-ph	Unsigned 16-bit value	MW22
blr4-ph	Unsigned 16-bit value	MW14
blr5-ph	Unsigned 16-bit value	MW24
blr6-ph	Unsigned 16-bit value	MW16
blr7-ph	Unsigned 16-bit value	MW26
blr8-ph	Unsigned 16-bit value	MW18
close-blr1-sol	Binary Tag	M4.5
close-blr2-sol	Binary Tag	M0.7
close-blr3-sol	Binary Tag	M4.7
close-blr4-sol	Binary Tag	M1.1
close-blr5-sol	Binary Tag	M5.1
close-blr6-sol	Binary Tag	M1.5
close-blr7-sol	Binary Tag	M5.3
close-blr8-sol	Binary Tag	M2.1
open-blr1-sol	Binary Tag	M4.6
open-blr2-sol	Binary Tag	M0.6
open-blr3-sol	Binary Tag	M5.0
open-blr4-sol	Binary Tag	M1.0
open-blr5-sol	Binary Tag	M5.2
open-blr6-sol	Binary Tag	M1.3
open-blr7-sol	Binary Tag	M5.4
open-blr8-sol	Binary Tag	M1.7
ph-1caustic-suda-p1	Binary Tag	A0.0
ph-1caustic-suda-p2	Binary Tag	A0.1
ph-2caustic-suda-p1	Binary Tag	A1.4
ph-2caustic-suda-p2	Binary Tag	A1.5
start-ph-1p1	Binary Tag	M2.6
start-ph-1p2	Binary Tag	M2.7
start-ph-2p1	Binary Tag	M4.2
start-ph-2p2	Binary Tag	M4.4
stop-ph-1p1	Binary Tag	M2.4
stop-ph-1p2	Binary Tag	M3.0



stop-ph-2p1	Binary Tag	M4.1
stop-ph-2p2	Binary Tag	M4.3
blr2-soda-v	Binary Tag	A0.2
blr4-soda-v	Binary Tag	A0.3
blr6-soda-v	Binary Tag	A0.4
blr8-soda-v	Binary Tag	A0.5
ph-1-soda-agitator	Binary Tag	A0.6
ph-2-soda-agitator	Binary Tag	A0.7
blr1-soda-v	Binary Tag	A1.0
blr3-soda-v	Binary Tag	A1.1
blr5-soda-v	Binary Tag	A1.2
blr7-soda-v	Binary Tag	A1.3
auto	Binary Tag	M3.3
start-ph1-agitator	Binary Tag	M3.5
start-ph-2-agitator	Binary Tag	M3.7
stop-ph1-agitator	Binary Tag	M4.0
stop-ph2-agitator	Binary Tag	M3.6
blr1-conductivity	Unsigned 16-bit value	MW30
blr3-conductivity	Unsigned 16-bit value	MW32
blr5-conductivity	Unsigned 16-bit value	MW34
blr7-conductivity	Unsigned 16-bit value	MW36
blr2-conductivity	Unsigned 16-bit value	MW38
blr4-conductivity	Unsigned 16-bit value	MW40
blr6-conductivity	Unsigned 16-bit value	MW42
blr8-conductivity	Unsigned 16-bit value	MW44
blr1-blowdown-v	Binary Tag	A2.0
blr3-blowdown-v	Binary Tag	A2.1
blr5-blowdown-v	Binary Tag	A2.2
blr7-blowdown-v	Binary Tag	A2.3
blr2-blowdown-v	Binary Tag	A2.4
blr4-blowdown-v	Binary Tag	A2.5
blr6-blowdown-v	Binary Tag	A2.6
blr8-blowdown-v	Binary Tag	A2.7
diverting-v1	Binary Tag	A3.0
ev1-conductivity	Unsigned 16-bit value	MW48



ev2-conductivity	Unsigned 16-bit value	MW50
ev6-conductivity	Unsigned 16-bit value	MW52
ev7-conductivity	Unsigned 16-bit value	MW54
ev9-conductivity	Unsigned 16-bit value	MW56
ev10-conductivity	Unsigned 16-bit value	MW58
ev14-conductivity	Unsigned 16-bit value	MW60
ev15-conductivity	Unsigned 16-bit value	MW62
ev17-conductivity	Unsigned 16-bit value	MW64
ev18-conductivity	Unsigned 16-bit value	MW66
ev22-conductivity	Unsigned 16-bit value	MW68
ev23-conductivity	Unsigned 16-bit value	MW70
ev27-conductivity	Unsigned 16-bit value	MW72
ev28-conductivity	Unsigned 16-bit value	MW74
diverting-v2	Binary Tag	A3.1
diverting-v6	Binary Tag	A3.2
diverting-v7	Binary Tag	A3.3
diverting-v9	Binary Tag	A3.4
diverting-v10	Binary Tag	A3.5
diverting-v14	Binary Tag	A3.6
diverting-v15	Binary Tag	A3.7
diverting-v17	Binary Tag	A4.0
diverting-v18	Binary Tag	A4.1
diverting-v22	Binary Tag	A4.2
diverting-v23	Binary Tag	A4.3
diverting-v27	Binary Tag	A4.4
diverting-v28	Binary Tag	A4.5
dumping-system-alarm	Binary Tag	A4.6
ph2-flash-tank-level	Unsigned 16-bit value	MW94
ph1-flash-tank-level	Unsigned 16-bit value	MW92
dumping-system-on	Binary Tag	M8.0
dumping-system-off	Binary Tag	M8.2
dumping-system-on/off	Binary Tag	M8.1
automatic-blowdown-on/off	Binary Tag	M8.3
automatic-blowdown-on	Binary Tag	M8.4
automatic-blowdown-off	Binary Tag	M8.5



blowdownalarm	Binary Tag	A4.7
ph1flashtankdrainv	Binary Tag	A5.0
ph2flashtankdrainv	Binary Tag	A5.1