Upgrading of Alum Preparation and Dosing Unit for Sharq Dijla Water Treatment Plant by Using Programmable Logic Controller System

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ABSTRACT

One of the important units in Sharq Dijla Water Treatment Plant (WTP) first and second extensions are the alum solution preparation and dosing unit. The existing operation of this unit accomplished manually starting from unloading the powder alum in the preparation basin and ending by controlling the alum dosage addition through the dosing pumps to the flash mix chambers. Because of the modern trend of monitoring and control the automatic operation of WTPs due to the great benefits that could be gain from optimum equipment operation, reducing the operating costs and human errors. This study deals with how to transform the conventional operation to an automatic monitoring and controlling system depending on a Programmable Logic Controller (PLC) and online sensors for alum preparation and dosing unit in Sharq Dijla WTP. PLC system will receive, analyze transmitting data, compare them with preset points then automatically orders the operational equipment (such as pumps, valves, and mixers) in a way that guarantees the safe and appropriate operation of the unit. As a result of Process and Instrumentation Diagrams (PID) that were prepared in this study, these units can be fully operating and manage by using Supervisory Control and Data Acquisition (SCADA) system.

Key Words: water treatment plant, alum-dosing unit, operation, SCADA, PLC, PID

تطوير وحدة إضافة جرعة الشب لمشروع ماء شرق دجلة باستخدام منظومة السيطرة المنطقية PLC

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الخلاصة

تعد وحدة تحضير وأضافة الشب من الوحدات المهمة في مشروع ماء شرق دجلة بتوسعيه الأول والثاني. حيث تتم أدارة عمليات تحضير وأضافة الشب في احواض التحضير بصوره يدوية بدءاً من أضافة مسحوق الشب وانتهاءً بعملية تعديل جرع الشب المضافة عن طريق مضخات اضافة جرع الشب الى أحواض المزج السريع. وبالنظر للتوجه الحديث في السيطرة والمراقبة الاوتوماتيكية لمشاريع الماء لما يوفره من منافع متعددة سواء في التشغيل الامثل للمعدات، وتقليل كلف التشغيل والأخطاء البشرية. فهذه الدراسة تعنى بتحويل نظام التشغيل التقليدي لوحدة تحضير واضافة الشب للمشروع الى منظومة سيطرة ومراقبة أوتوماتيكية اعتمادا على جهاز سيطرة مبرمج (PLC) ومتحسسات. حيث تقوم هذه المنظومة باستلام وتحليل البيانات المنقولة ومقارنتها بعدد من القيم مسبقة الضبط وتوجيه الاوامر للمعدات التشغيل (مثل المضخات والصممات واجهزة المزج) بما يضمن التشغيل الامثل والأمن لهذه الوحدة. كنتيجة لمخططات أجهزة العمليات PID المعدة في هذه الدراسة، يمكن لهذه الوحدات ان تشغل وتدار بواسطة منظومة التحكم الاشرافي واستحصال البيانات SCADA.

1. INTRODUCTION

Many Water Treatment Plants (WTP) in Baghdad city have problems coming from the poor quality of raw water and higher concerns of finished water quality. Many solutions can be applied to the existing WTPs to improve their performance and efficiency. One of them can be accomplished through automating them.

An automated process control system as stated by the website of **(Opus International Consultants)** will allow treatment plants to be either unmanned or manned for only part of a working day. They utilize on-line instrumentation and controllers to continuously monitor and control the quantity or quality of the process inputs and outputs. Continuous control using sensitive and accurate instruments that supply data to well-programmed controllers should provide a steadier and more consistent product from the various stages of the treatment plant that could be achieved with manual control.

As a result of progression in plants operation and water quality monitoring technology, the use of instrumentation and automatic control systems are increased in the last decays. This trend is not surprising because the proper use of these systems can reduce labors; chemicals used; and improve the treatment process efficiency, reliability, data acquisition, and recording, **Syed, 1999**.

The aim of this study is to upgrade the alum preparation and dosing unit in Sharq Dijla WTP to automation operation and control to gain the advantages mentioned in many studies such as **Er. Ravinder, et al., 2016, Sadegh Vosough, et al., 2011, Gergely EI, et al., 2009, and Nikolić ., et al., 2008**.

2. ANALYSIS OF AN AUTOMATION PROCESS CONTROL SYSTEM

2.1 SCADA System

SCADA (Supervisory Control and Data Acquisition) system is an extremely important application of computer technology that has created huge gains in productivity and efficiency in the processing industries. Where SCADA system is an assemblage of computer and communications equipment designed to work together for the purposes of controlling a commercial process, like treatment processes of water and wastewater. Besides control, SCADA systems also perform monitoring, data logging, alarming and diagnostic functions, so that large complicated process systems can be operating in a safe manner and maintained by a relatively small staff, **Stephan, 2007**.

The SCADA automation system includes always several functions, e.g., signal sensing, control, human-machine interface, management, and networking, **Munro, 2008,** and **Gergely, et al., 2009**.

SCADA System's components comprised of one or more central processing units, like the PLCs devices, RTU's (Radio Telemetry or Remote Terminal Units), Input / Output (I/O) Subsystems, Video monitors, field sensors, control devices. Also, they include lots of software that drives the I/O, runs the control algorithms, generates control outputs, displays graphics and monitored values, senses alarm statuses, and stores the monitored points in a series of data files that can be archived and recalled at a later time for analysis or process verification, **Stephan, 2007**.

2.2 I/O Subsystems

Any type of SCADA systems, whether it is laboratory-sized, planet-sized or, a countywide distributed system, is going to consist of measurement points or variables that need to be monitored. The measurements will be made using electronic sensors and instrumentation, (pressure, temperature, flow, position, etc) and will be brought into the SCADA system through the Input / Output (I/O) subsystem. The input side is comprised of; Analog Inputs (AIs), which accept a continuous input of an analog signal, (usually 4 to 20 mA, 0 to 5 VDC, or 0 to 10 VDC) from a transmitter; and Discrete Inputs (DIs), which typically accept an on or off signal from a switch or contact closure, **Warnock, 1998**.

On the output side, there are Analog Output modules (AO), which send a continuous signal to modulating control elements, like control valves and motor speed controllers; and Discrete Outputs (DO), which send signals to start and stop motors and open and close block valves. The I/O modules may be “local” or close-coupled to the CPU (in the same rack or cabinet) for a small system, or the I/O may be “remote”, i.e., distributed out in the field with electrical cabling. In some cases, radio modems used to connect the I/O to the CPU wirelessly, **Stephan, 2007**.

2.3 Programmable Logic Controller (PLC)

A programmable logic controller (PLC) can be defined as a digital computer used for automation of industrial processes, such as control machinery on factory assembly lines, **Warnock, 1998**.

The PLC is a microprocessor based device with either modular or integral I/O circuitry that monitors the status of the field connected "sensor" inputs and controls the attached output "actuators" (motor starters, solenoids, pilot lights/displays, speed drives, valves, etc.) according to a user-created, logic program stored in the microprocessor's battery-backed RAM memory, **Charles, 1999**.

PLCs were originally developed in the late 1960s for factory application to replace relay logic, where older automated systems would use hundreds or thousands of relays, while a single PLC can be programmed as a replacement, **Charles, 1999**.

PLCs are evolving into very capable and cost-effective process controllers and are rapidly becoming very popular for nearly all process control applications, including serving as RTU’s for SCADA systems, **Stephan, 2007**.

3. THE STUDY AREA

Sharq Dijla WTP is a one of Baghdad city WTP located in the north of Al-Adamiya district on the east bank of Tigress River, which supplies potable water to Al-Rusafa area. It consists of two stages:

3.1 First Stage

Execution since 1978 produces effluent treated water in design capacity of (125 MGD) about (473,126 m^3/day) that contributed with other existing WTPs to cover water demand until 2000. It consists of conventional surface water treatment units for the physiochemical process as (intake and low lift pumping station, coagulation and flocculation, sedimentation, filtration by gravity rapid sand filters, post chlorination, storage in the ground storage tank, and high lift pumping station).

There were three preparation basins used for mixing clear water with the powder alum to produce an alum solution through compressed air generated by two air blowers (one duty and the other standby). The solution pumped toward the distribution basin and dispersed into by nozzles in order to be mixed hydraulically with influent raw water. All these processes were operating and controlled manually as schematically illustrated in **Fig. 1**.

3.2 Second Stage

Because of lag of time to execute the biggest WTP “Al-Rusafa WTP” which has been planned to operate in 2000 to supply about (240 MGD), the second stage have been accomplished in 2007 to supply more than (50 MGD) and recover the lag of potable water demand. It consists of the same of the stage one conventional process unless using of pressured filters, and supply its effluent treated water to the same existing ground storage tank.

In the chemical building, the alum powder added first to the two preparation basins, mixing with clear water to prepare alum solution by a turbine paddle mixer. The primary prepared alum solution discharged to the alum saturation basins for further pneumatic mixing by air blowers. The solution injecting to mix with influent raw water into the flash mixing chamber. Same as the first stage, the process operated and control manually as schematically illustrated in **Fig. 2**.

4. RESULTS AND DISCUSSION

Determining the optimal coagulant dosage is vital, as insufficient dosage will result in unqualified water quality. Traditionally, jar tests and operators own experience have been used to determine the optimum coagulant dosage. However, jar tests are time-consuming and less adaptive to changes in raw water quality in real time. When an unusual condition occurs, such as a heavy rain, the stormwater brings high turbidity to the water source, and the treated effluent quality may not satisfy the drinking water quality standards, caused by the complexity of the conventional operation method adjusting with time to reach a proper dosage. Therefore, it recommended using online monitoring devices with an automatic PLC-based control system to adjust the alum dosage continuously according to the variation in flow rates, turbidities, and allowable alum residual. Additionally, there will be an ability to control the alum preparation and dosing equipment manually either from the local control panel or through the suggested operator monitoring and control device in the Operator WorkStation (OWS) in case of maintenance and inspection. This has been done by the following methodology for each stage:

4.1 Alum Preparation & Dosing Units Instrumentations

The following devices can be used to control the alum preparation and dosing manually through the OWS, Local Control Panel (LCP) when the manual mode is selected or automatically through the PLC-CB when the automatic mode is selected.

- Alums solution preparation basins can be supplied with unloading silo equipped with motorized unloading valve and an electronic weighing system with a digital display. This allows any quantity of alum powder to discharge from the automatically controlled silo to provide an accurate indication of what remains inside the silo. Besides, it provides the ability to control the alum powder discharge through LCP or through OWS.
- The PLC-CB would provide the ability to control the alum preparation and dosing automatically.
- An ultrasonic LIT would be used on the alum preparation basins to provide the ability to control the solution level automatically by connecting the signal from the LIT with PLC-CB.
- Density Indicator Transmitter (DIT) would be used in the preparation basins to monitor the alum solution concentration. The signal of DIT should be connected with the PLC-CB to control the alum dosing automatically.
- LCP of water service pumps feeds the preparation basins, and the LCP of air blowers should be connecting to the PLC-CB in order to control their operation automatically when the automatic mode is select.
- The signal of the Turbidity Indicating Transmitter (TIT) on the low lift pumps wet-well should be connecting to the PLC-CB for the automatic control of the dosing operation.
- The setpoint of alum purity should be programming within the PLC-CB to automatic compute the alum solution corrected dosage depending on the alum purity percent.

- Alum Indicating Transmitter (ALIT) of clarified water should be connecting with PLC-CB to reduce automatically the alum solution dosage when it receives a signal referring that the aluminum concentration exceeds the allowable limit with freezing the dosage modification until the next treated batch of flow reaches the ALIT.
- A manual air direction valves should be replaced with electrically actuated valves to provide an automatic control discharged air to alum preparation basin, in which the alum solution preparation accrues when the automatic mode operation is selected.
- Flow Indicating Transmitter (FIT) signal of the influent raw water flow should be connected to the PLC-CB to the alum dosing automatically when the raw water flow changes.
- Since dosing pump speeds are manually control, should replace them by variable speed pumps that are capable to control either automatically through PLC-CB or manually, through LCP or through the operator control device in the OWS.
- When selecting local mode, the service pumps, air blowers, and the powder alum unloading will be accomplished manually through the operator by the Local Control Panels (LCPs). While in the remote mode, the operator by the operator control and monitoring device in the OWS will choose whether the preparation and dosing are accomplished automatically through the PLC-CB by selecting the auto mode or through the operator control and monitoring device in the OWS by choosing the Hand mode.

4.2 Automatically Operation

- Before selecting the auto mode, the three preparation basins must be set with priority within the PLC-CB. Each basin priority is selected depending on the alum solutions preparation age. The basin with longer alum solutions preparation age is set with the first priority for feeding dosing pumps. Other basins with lesser preparation age are set as second and third priority respectively. In case of empty or equal preparation ages of basins, random priority can be selected by the operator or by SCADA systems program.
- After selecting the Auto mode, the PLC-CB detects the alum solution level in the three basins to start the alum preparation within the empty basins.
- The alum feeding from the basins would be depending on the basin priority degree. When the auto mode selected, the alum solution feeding will be starting from the basin that set as the first priority until empty to selecting the second one. In addition, when preparation basin emptied, the PLC-CB sends an order to close its related feeding valve and shut down pumps. Then starting to refill by auto or manual selecting alum dosing and clear water to prepare a required solution for continuous operation. The alum dosage set points have been depending on data analysis received from TIT for water quality with the specific time delay.
- To start the alum preparation, the PLC-CB sends firstly an order to the silo unloading-valve to unload the pre-set value of the alum powder. Also, it sends an order to operate the water service pumps to fill the tank with specific water level controlled LIT signals. Then sends orders to operate the air blower and opening the air inlet valves of the basin to start mixing for a preset period.
- The PLC-CB will use the FIT, DIT, ALIT and TIT signals to calculate the alum required feeding rate and modify the dosing pumps speed in order to obtain the required alum dosage. Calculating the alum feeding rate will be according to the following equation **(Syed, 1999)**:

(1)

$$Q_a = \frac{C_r Q}{\rho_a P_{\%}}$$

Where:

Q_a = Alum feed rate (L/hr),
C_r = Alum required dosage (mg/L),
Q = Raw water flowrate (m^3/hr),
P_a = Alum concentration in preparation basin (kg/m^3),
$P_{\%}$ = Alum purity (%).

- This process proceeds automatically until:
  a) Manual operation sets on the OWS or LCP,
  b) The PLC-CB receive the signal from LIT in-ground storage tank indicating that is full,
  c) Low turbidity level of raw water indicating by TIT in the low lift pumping wet-well,
  d) No response for low alum powder level alarm on the silo,
  e) Instrumentations damage without alarm response for repair,
  f) Emergency shutdown of WTP.

Fig. 3 and **Fig. 4** reveal the upgrading schematic control loops as Process Instrumentation Diagrams (PIDs) for alum preparation and saturation tanks in stage one and stage two of Sharq Dijla WTP respectively.

5. CONCLUSIONS

It is possible to transform the conventional Monitoring and Control (M&C) system with an advanced automatic M&C system by using a PLC and a number of the online sensors. If applying this system to the chemical building in the Sharq Dijla WTP, many benefits would be gained such as:

- The strength security through ovation advance security features,
- Reduce chemical usage and optimized operation,
- Maximize energy saving through integrated, real-time process and equipment information coordinated that interface wide energy management programs,
- Achieve higher productivity, reducing operation costs, and better utilization of staff with advanced process automation, communication, and information management.

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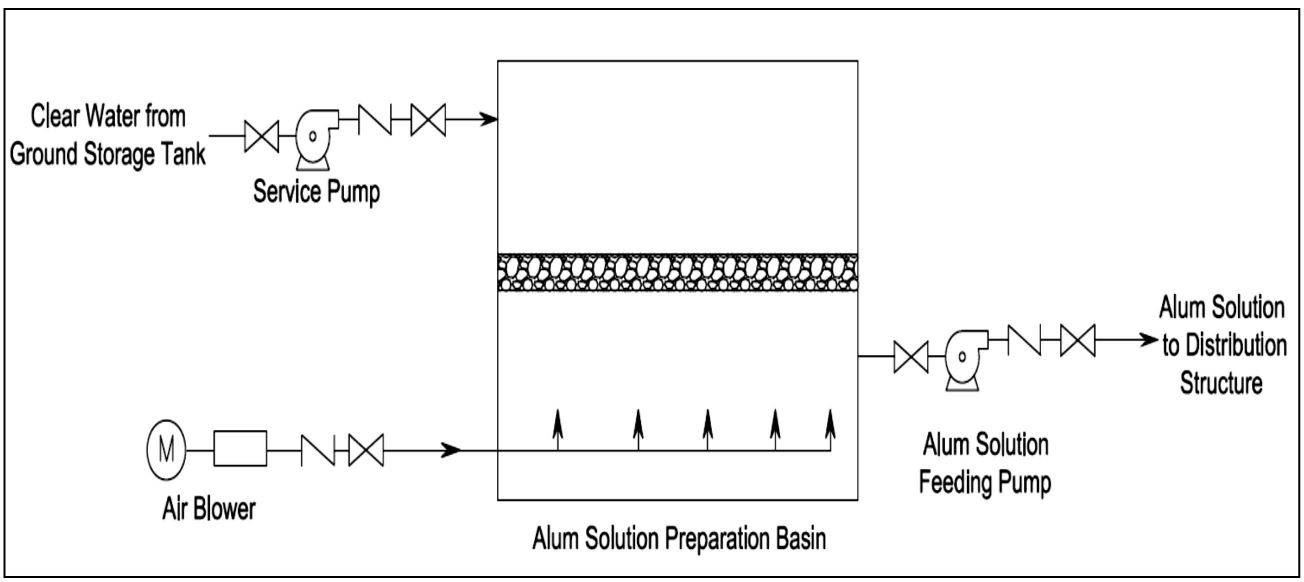


Figure 1. Schematic diagram of alum preparation and dosing unit in Sharq Dijla WTP – Stage One.

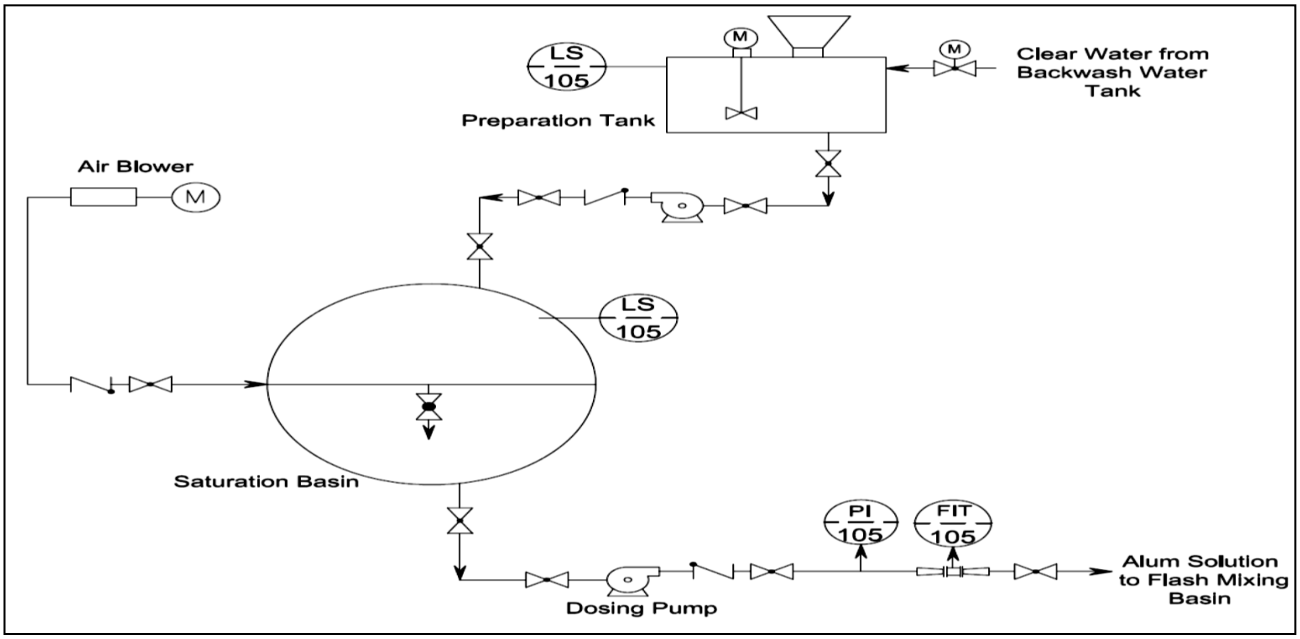


Figure 2. Schematic diagram of alum preparation and dosing unit in Sharq Dijla WTP – Stage Two.

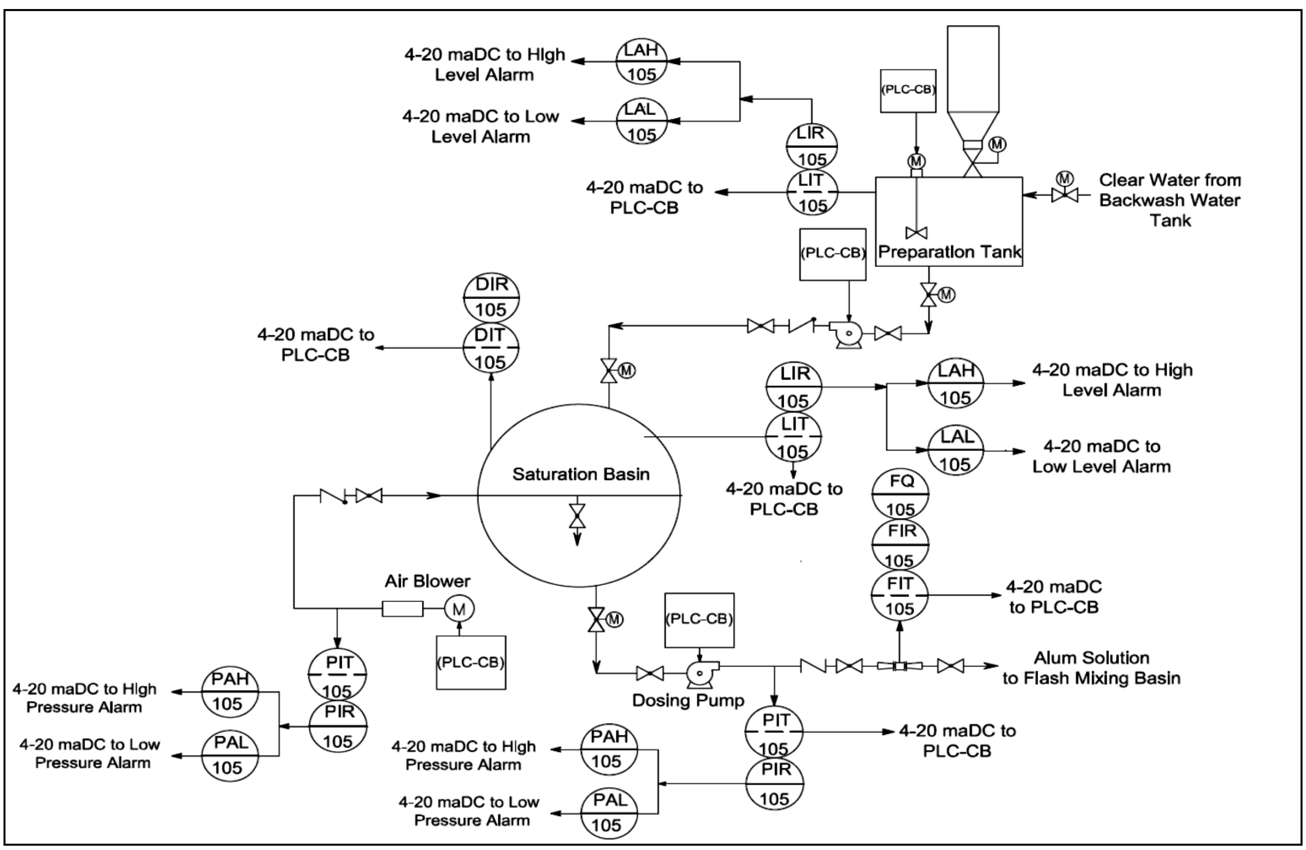


Figure 3. PID to upgrading alum preparation and dosage process – Stage One.

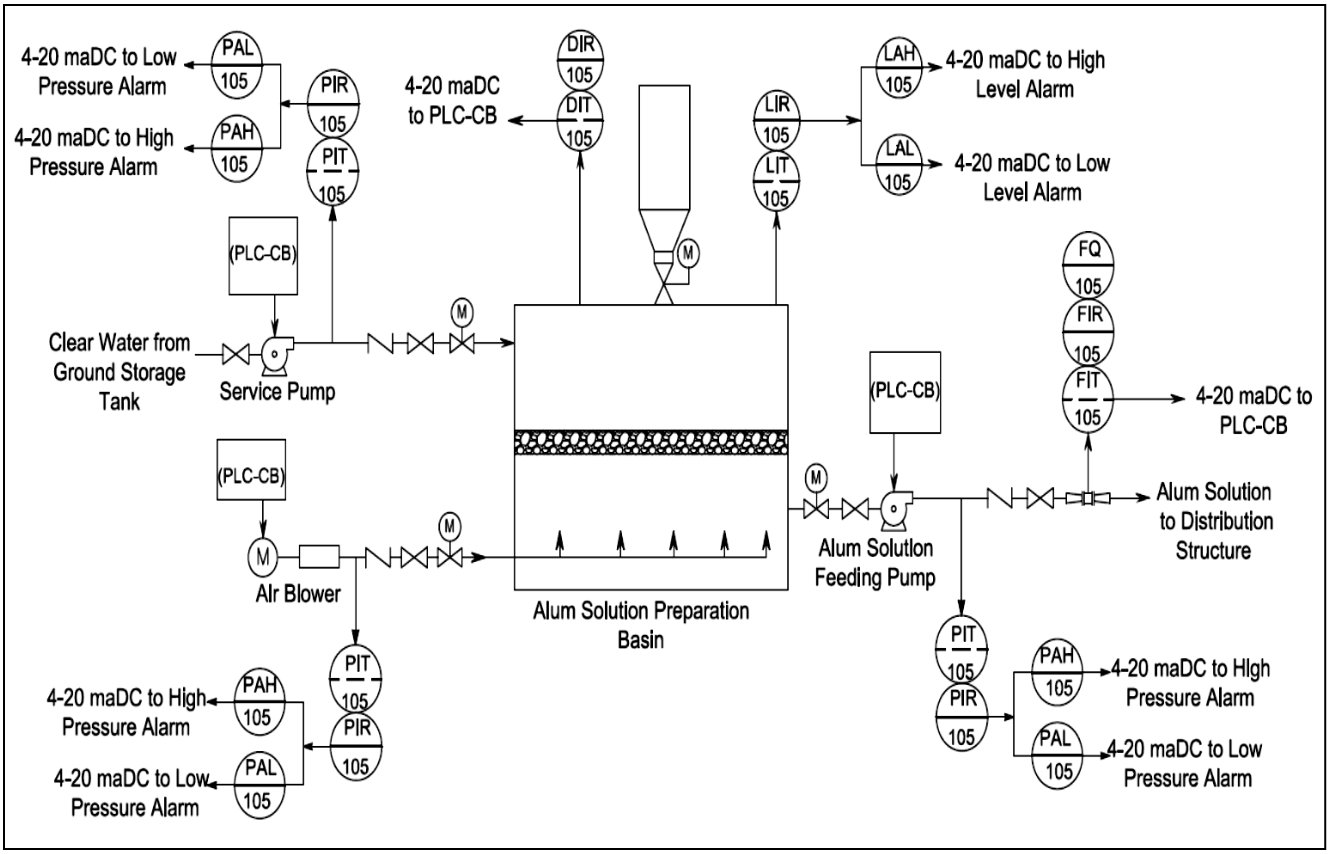
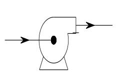
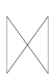
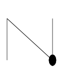
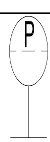
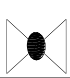
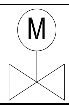
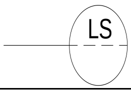
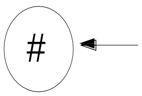
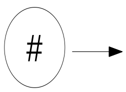
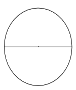
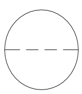
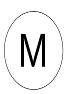
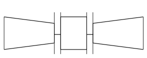
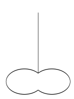
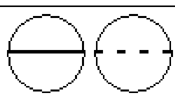


Figure 4. PID to upgrading alum preparation and dosage process – Stage Two.

Symbol	Legend	Definition
	Pump	A device for raising, compressing, or transferring fluids.
	Gate Valve	A valve in which the closing element consists of a disk that slides across an opening to stop the flow of water.
	Check Valve	A valve designed to open in the direction of normal flow and close with reversal of flow.
	Pressure Indicator	A device for measuring water pressure.
	Ball Valve	A valve consisting of a ball with hole resting in a cylindrical seat to allow the water to flow when the

Symbol	Legend	Definition
		valve is opened and when the ball rotates 90°, the valve is closed.
	Motor Actuated Valve	*A Valve operated* automatically, by hand, or by a special mechanism.
	Level Switch	A device used to detect the *level* of liquid within a tank.
	Signal to control loop	
	Signal from Control Loop	
	Solid Line Indicating Instrument Mounted in Central Control Panel	
	Dashed Line Indicating Instrument Mounted in Local Control Panel	
	Motor	A machine or an engine that produces or imparts motion.
	Ultrasonic Flow Meter	An ultrasonic flow meter measures the velocity of any liquid through a pipe using ultrasonic transducers.
	Mixer	A device for mixing water.
		Chemical Station

list of abbreviation		list of abbreviation	
ALIT	Aluminum Indicating Transmitter	O	Output
CB	Chemical Building	OCP	Operator Control Panel
D.P	Dosing Pump	OWS	Operator Work Station
DIR	Density Indicating Recorder	PAH	High-Pressure Status Alarm
DIT	Density Indicating Transmitter	PAL	Low-Pressure Status Alarm
EWS	Engineer Work Station	PC	Personal Computer
FIR	Flow Indicating Recorder	PI	Pressure Indicator
FIT	Flow Indicating Transmitter	PIR	Pressure Indicating Recorder
FQ	Flow Totalizer	PIT	Pressure Indicating Transmitter
HMI	Human Machine Interface	PLC	Programmable Logic Controller
I	Input	RTU	Radio Telemetry or Remote Terminal Units
LAH	Level Alarm High	S	Signal
LAL	Level Alarm Low	SC	Speed Control
LCP	Local Control Panel	SCADA	Supervisory Control And Data Acquisition System
LI	Level Indicator	SDWTP	Sharq Dijla Water Treatment Plant
LIR	Level Indicating Recorder	SI	Speed Indicator
LIT	Level Indicating Transmitter	TIT	Turbidity Indicating Transmitter
LOR	Local Off Remote	VCP	Vender Control Panel
LPE	Low Pressure Element	VDC	Volt Direct Current
LS	Level Switch	WTP	Water Treatment Plant
M	Motor	YA	Fault Status Indicator
maDC	Milliampere Direct Current	YL	Run Status Indicator
NA	High Torque Status Alarm		