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PLC based Automatic Distillation and Collection of Ethanol-Water Solution

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Abstract

This paper demonstrates the design and implementation of a binary distillation and collection of Ethanol-Water solution. The PLC based distillation and collection of the liquids is one of the innovative industrial automation projects. The conventional design contains a PLC based automated model of liquid distillation and collection systems, where PLC (SIMATIC S7-300) is used as the controlling brain of the system and distillation and collection are the two main units of the designed system. The distillation control system separates the homogeneous mixture of water and alcohol (ethanol) by comparing the current temperature of the solution of the continuous solution feeding to the column with the boiling points of individual compounds and collection system collects the separated solvents into the bottles placed on the conveyor belt. The monitoring and controlling of the whole systems are evaluated on the basis of temperature and level of the specific units under consideration of atmospheric pressure. Thus the accurate working of process control can lead to smooth operation of the system, preventing unwanted failures, shutdowns and providing notable cost saving and reliability.

Keywords: Collection, Distillation, Ethanol-Water Mixture, PLC SIMATIC S7 300

1. Introduction

The availability of smart solid state devices has provided control systems which can diminish the maintenance and revamp productivity at a significant amount and different techniques are adopted for the purpose[1]. One of the most common method in solid state controls that offers flexible and systematic operation to the user is through programming based Automation system utilizing programmable controllers[2,3]. A Programmable Logic Controller (PLC) is a device that was invented to replace the necessary sequential relay circuits for machine control. The basic elements of a PLC include input modules, a Central Processing Unit (CPU), output modules and a programming device[4]. The PLC structure diagram is shown in Figure 1. PLCs are used in almost every aspect of industry to expand and enhance production[5]. The functionality of the PLCs has evolved over the years to include capabilities beyond typical relay control. Sophisticated motion control, process control, distributive control systems, and complex networking have now been added to the PLC's functions[6]. The PLC was developed as a more streamlined, flexible and realistic alternative to switch boxes and relay panels. It is dedicated only to specific tasks in the factory and to maintain its robustness and consistent performance in challenging environments. On the other hand, computers serve a higher level role for complex calculations, monitoring as well as user interface to the PLC, it couldn't operate reliably as a PLC in harsh factory conditions.

Siemens S7-300 PLC belongs to the SIMATIC®S7 family is a programmable controller, widely used as the automation tool in most of the industries[7,8]. The compatible software for this PLC is Step7; it provides the programming environment for ladder diagrams and hardware configuration[9], along with Real Time Monitoring of programmed blocks[10].

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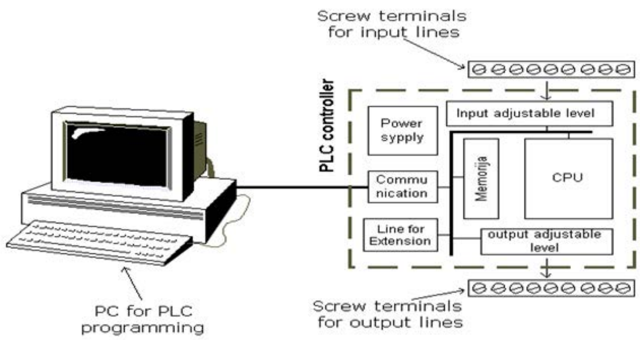

Figure 1. PLC structure.

Distillation is a process used for the separation of the liquids from a homogeneous mixture. Ethanol-water mixture is very common and its properties[11] are concerned whenever the separation is required at most of the cases, usually in sugar industry from the fermentations of sugars, so this mixture has been taken as an object in this project. Binary Distillation, a simple distillation technique, is used for the purpose[12]. Since alcohol is lighter than water along with lower vapor pressure, so it evaporates earlier[13–15]. The distillation operation is totally dependent on temperature of mixture. Hence fine control of this process variable is basic requirements to get the desired purity levels of separation. Several chemical distillation techniques have been adopted over the years for separation of the Ethanol-water mixture[12–16]. Distillation using fatty acids have been used in[13]. Hollow fibers are adopted in[14]. Distillation techniques using salt and solvent as entertainer have also been used previously in[15]. However, in the modern era, the wide applications of automation and subsequent depletion in the man machine interfacing demands the utilization of control systems in the distillation process. Automation in the distillation and collection process can reduce the maintenance, generates the quality products, and improves productivity. S7-300 PLC provides such qualities and a user friendly industrial electronic system for the process control. PLC has been used for the automatic control of the distillation column, however no provision has been provided for the automated collection of the liquids[17]. The conveyer belt design and methodology has been described in which Siemens S7-200 is used as controller[16].

The paper provides the solution to improve the service and production of industry by managing the whole system automatically. It provides the lab-scale design of continuous monitoring and controlling of the distillation of homogeneous mixture of ethanol-water and the collection of separated solvents as well.

2. Proposed Approach

The proposed approach comprises of the physical design and operation of the system, and the programming of the operational sequences of the required process.

2.1 System Design

SIMATIC S7-300 PLC has been used as the main automation tool in the system. It has proven to provide flexible automation and control to several applications[18]. It is a control system with functions to control logic, sequencing, timing, arithmetic data manipulation and counting capabilities.

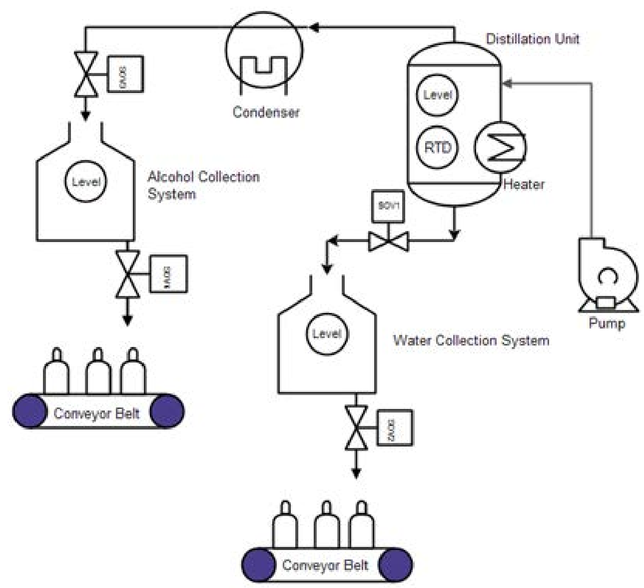

Figure 2. System design.

The 220V pump feeds the Ethanol-water mixture in the distillation unit. Liquid level control switch maintains the level of the distillation unit. The float level sensor is used for that purpose which sends a high signal of DC 24V to the PLC when the tank is empty and a low signal when the tank is full. A heater is used for providing heat energy to the mixture for changing the state of alcohol from liquid to gas. The solenoid valve SOV1 is connected at the bottom of the distillation tank which controls the flow of the separated water and let it to be filled in its separate tank. The most important part is the temperature sensor which measures the actual temperature of the tank; PT100 RTD has been chosen in this design to sense the Temperature (C^o). The advantage of using this sensor is that it can be directly connected to the S7-300 PLC analog input module SM 331 which is 8-channel/16-bit RTD module whose resolution is based on Sigma-Delta principle. The interfacing of this sensor with PLC provides the decimal values on which system's conditions are set accordingly.

The lower side of distillation unit is interfaced with water collection system through solenoid valve SOV1. An axial fan is attached in the water tank for the purpose of cooling. The collection unit comprises of the conveyer belt that is operated through a 24V DC dear motor. The collecting system provides the storage of water with collection rate of one bottle per 15secs. There is a pause of 3 seconds for replacing the filled bottle with empty one. Proximity Sensor is used which assesses the position of the bottle when it reaches under the filling solenoid valve, and also to start/stop the conveyer belt.

Evaporated Alcohol is then passed through the condenser that changes its gaseous state back into the liquid. Liquid Alcohol is then also collected in similar manner through collection tank to the conveyer belt bottles. The overall design of the system is shown in the Figure 2. Table 1 and Table 2 represent the operational characteristics of the DC gear motor and the RTD.

Table 1. DC gear motor electrical characteristics

Maximum voltage	Mass	OPERATING VOLTAGE	STARTING CURRENT	RUNNING CURRENT
24V	2.3kg	24V	5A	2-3A

2.2 Programming

Since the system described in this paper is controlled by Siemens S7-300 hardware so its compatible software is SIMATIC Step 7 and hence used for programming of the system. The routines are programmed and saved in blocks which are then downloaded to the PLC. Step 7 also provides a Real Time Monitoring system and supports three languages and these are Ladder Language, FBD (Functional block diagram), STL (Statement List).

Ladder programming is the most common and sophisticated programming used for many applications and it can easily be modified if needed at any time. So Ladder programming techniques are used in this system to acquire the desired response. The following Figure 3 shows the glance of Step 7 environment, and Figure 4 shows the programming flowchart followed in the Step 7 software using ladder programming**.**

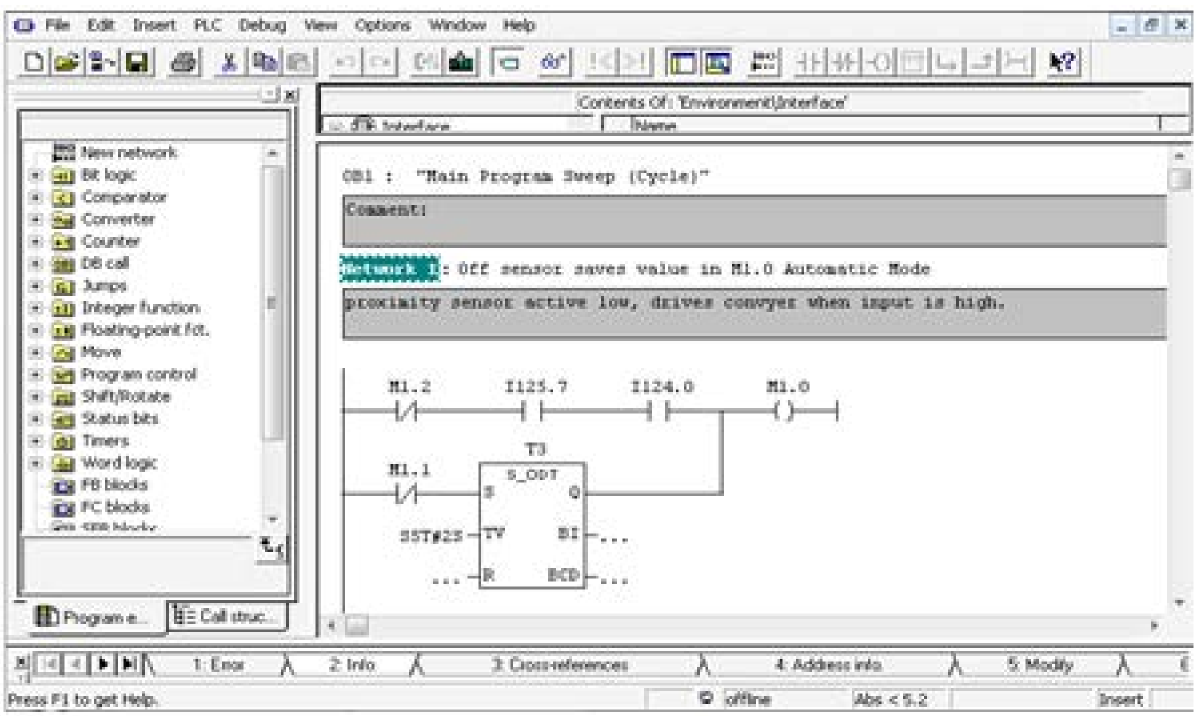

Figure 3. Step 7 software environment.

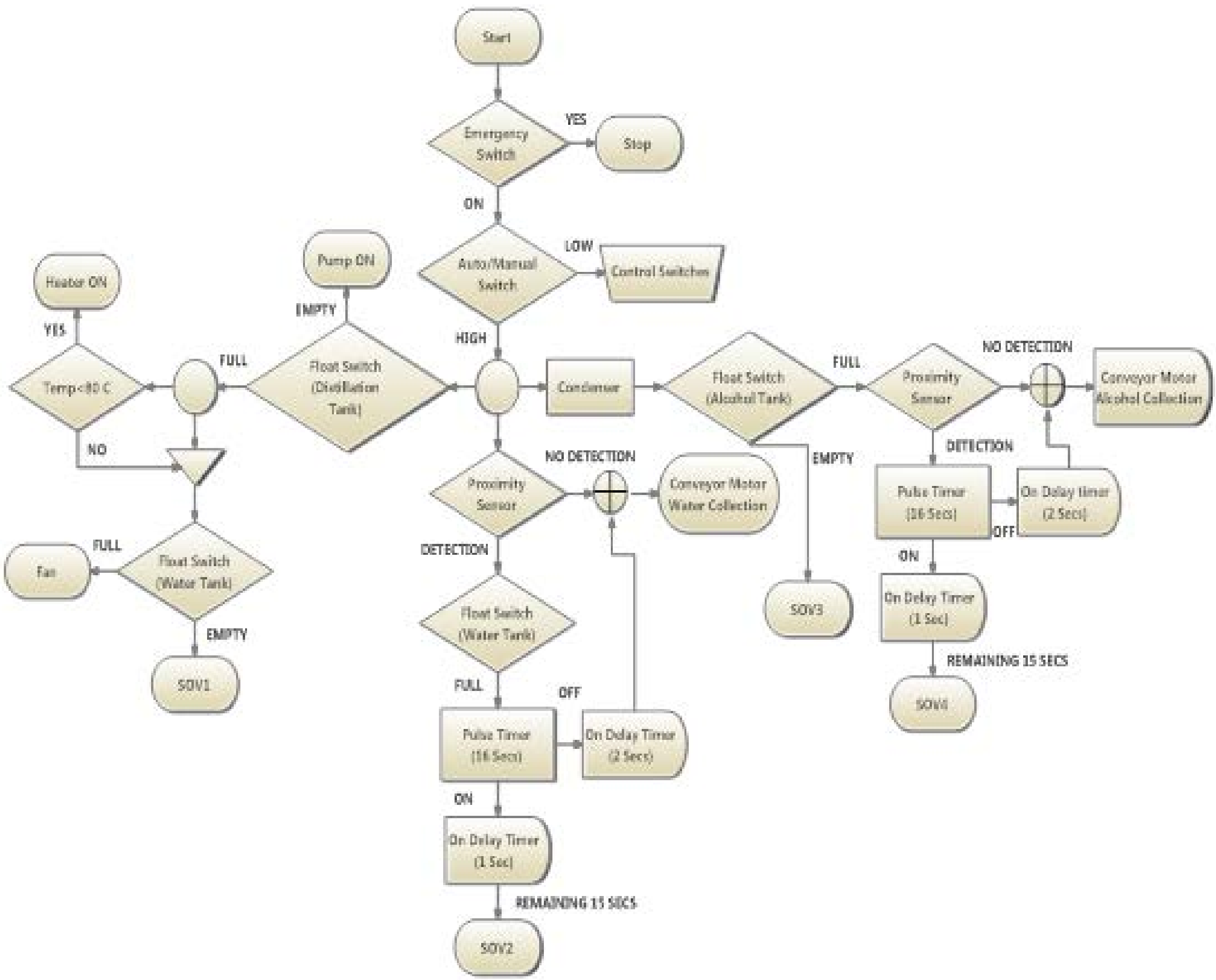

Figure 4. Programming flow chart.

3. Experimental Analysis

Initially, the distillation tank is empty, so the level switch sends high signal to the PLC. The PLC activates the pump, which pumps the solution and fills the distillation tank; the solution is being filled until the level switch sends a low signal to the PLC. For experimental purpose 1 liter of Ethanol-Water solution was taken which was pumped to the distillation tank and took approximately 1 minute to reach a certain level. After that, the heater is turned on at the low signal of the level switch until the temperature of the tank reaches at 80°C which took approximately around 10 minutes, the temperature of miscible solution also depends upon the concentration of the Ethanol, and greater the concentration greater time will be taken to vaporize the Ethanol.

At temperature 78°C the alcohol starts to vaporize, the temperature of solution remains same till the last drop of alcohol vaporizes. When the temperature of solution increases from 78°C to 80°C, it may be concluded at that time the alcohol is completely vaporized leaving behind only water in the distillation tank[19]. An RTD is used whose reading is continuously monitored and accordingly an action is performed by the PLC. The RTD input signal is continuously updated and PLC executes the signal by comparing with the set point. The following Table 2 shows the decimal values obtained from STEP7 software when RTD is interfaced with PLC at certain temperature which shows a change of 16 decimal values per degree Celsius and Figure 5 shows the lineariqty of RTD.

At 80°C, the PLC turns off the heater, and turns the position of SOV1 to open, and water would flow into the

Table 2. Temperature vs. decimal values

Temp	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Decimal Values	5168	5248	5328	5408	5488	5568	5648	5728	5808	5888	5968	6048	6128	6208	6288	6368

water collection unit. It serves as drainage for distillation tank and inlet for water collection tank. An SOV2 valve is connected at the bottom for collection of the water in the bottles placed on conveyor belt. The vaporized alcohol is passed through the condenser, the condenser changes the gaseous state back into the liquid state and pure alcohol is collected in separate tank. SOV3 is inlet valve of the alcohol collection tank. Similar conveyor system is also used here for collection of alcohol in bottles through SOV4. The overall PLC operation cycle for a single turn is about 12 minutes and 18 seconds. Table 3 presents the overall operational analysis and sequences of the proposed system.

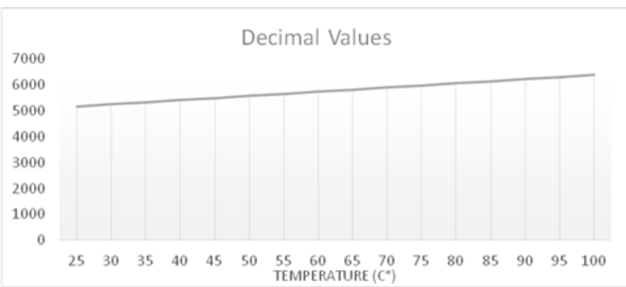

Figure 5. RTD linearization.

4. Conclusion

The paper has presented the automated system for the distillation of the Ethanol-Water mixture based on PLC controller. The design of collection system for the Separated liquids has also been presented. The paper presents the electric solution to the complete distillation and collection process from filling up of distillation tank to the collection of separated liquids in the bottles through the conveyer belt. The proposed approach can also be used for the distillation of most of the liquid mixtures. The presented analysis also successfully demonstrates the potential of the idea

5. Future Work

An HMI interface can also be implemented. The whole process can be controlled and monitored graphically. This proposed idea only controls a process named Distillation and fills those separated solvents in the bottles automatically. It can also be used in combining with the process named Liquid-Liquid extraction, that needs a distillation to separate the extracted material and the solvent that is used for the extraction of product from a compound.

Since this conventional method can only separate a miscible solution which is combination of two solvents and cannot work if the solution contains some extra elements, this binary distillation technique can be converted into fractional distillation column which can provide more purity level.

Table 3. Operational analysis of the designed System

Level Switch	Temperature °C	Pump	Heater	Condenser	SOV1	SOV2	SOV3	SOV4	Conveyer Belt
On	23	On	Off	Off	Off	Off	Off	Off	Off
Off	70	Off	On	Off	Off	Off	Off	Off	Off
Off	78	Off	On	On	Off	Off	On	On	On
Off	80	Off	Off	On	On	On	On	On	On

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