

Supervision, control, and data acquisition system of a heat exchanger

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ABSTRACT

Today, when industry 4.0 is already being talked about, and its advantages at the organizational level, there are still industrial processes that show a lack of automatic regulation mechanisms, which means that an optimal operating process is not guaranteed, nor that monitoring and supervision capacity. In this sense, the purpose of the article is to demonstrate the feasibility of the integration between the programmable logic controller and the Arduino nanocontrollers, this as an alternative to automate a concentric tube heat exchanger, for monitoring and data acquisition through a supervision, control and data acquisition system. The integration is shown through the design and implementation of a temperature transducer made up of a MAX6675 converter module and an Arduino Nano controller, which is amplified through its pulse width modulation (PWM) interface and the integrated TL081CP and coupled to the analog inputs of the automaton. As a result of the experimental tests, it was possible to determine that the flow rate of the automated system is directly proportional to the drop or difference in temperature in the hot fluid and inversely proportional to the increase in temperature in the cold fluid, verifying the effectiveness of the automated heat exchanger.

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1. INTRODUCTION

Heat exchangers, during these times have taken on significant relevance, due to their application and use in various industrial processes, such as in the metallurgical industry, chemical processing plants, industrial refrigeration processes, oil cooling systems for steel production, heat processing of materials and even in the food processing industry [1]. The main objective of the heat exchanger in these industrial processes is to develop an adequate temperature management, that is, the utility fluids to heat or cool materials require a specific heat treatment, in which the temperature of each stream is modulated process sui

For each stage [2]. The decision of which service or operation stream should be exchanged is a rather complex problem, since it depends on the amount of streams that need to be cooled or heated, as well as the characteristics of the fluids such as heat capacity, viscosity and conductivity, which depend on temperature, so monitoring this last parameter is quite important in these processes [3], [4]. In a heat

exchanger it is important that the operating parameters are constantly monitored, since their variation or alteration negatively affects in a direct way the optimal functioning of the production process, which makes use of flows or currents of different temperature values; leading to the alteration of the quality of the final product [5]. Thus, the use of industrial automation becomes relevant in the control and regulation of the variables of various equipment, plants or industrial processes, since it guarantees to keep the controlled variable within a range of pre-established values, known as set-point values [6]-[8]. Thus, by automating a heat exchanger through a programmable logic controller (PLC), it is possible to self-regulate the behavior of temperature through a connection logic between sensors and actuators, ensuring that it is always within a range of optimal or desired operation [9]. It should be noted that in a heat exchanger it is necessary to have a temperature measurement not only at one point, but at all points where the process streams need to be heated or cooled [10]. Thus, through various temperature sensors, connected at different points of the heat exchanger and connected to the inputs of the PLC, it is possible to digitize the signal so that after processing it, carry out the appropriate scaling so that the actuators carry out a process of regulation through a control action [11]-[13].

In heat exchangers, as well as in any other industrial process in which the temperature is controlled, it is necessary to use sensors, although in many cases the so-called conventional sensors have certain deficiencies, such as lack of precision or are very susceptible to noise [14], [15]. Nowadays, the treatment or processing that is given temperature is evolving, once the signal is captured; in some cases, Arduino controllers or Rabbit processors are used, improving the quality of the signal [16]-[18]. It is possible that the signal acquired by the sensors that are integrated into the Arduino controllers, it is possible to integrate them into a transmitter so that they can be part of a supervision and monitoring system, either wired or wireless [19], [20].

With regard to the data acquisition, control and supervision systems (SCADA), these systems are widely used in the monitoring of parameters that determine the optimal operation of plants and industrial processes, they allow to generate representations and historical data in real time of the operation of the system under analysis [21]-[23]. In this regard, in [24], [25] it is specified that these systems also have the ability to provide control signals that correct or regulate the behavior of the controlled variable of an industrial process. With regard to heat exchangers, SCADA systems are integrated in such a way that they not only monitor the temperature to generate an alarm signal in each operating or service current in the event of a variation with respect to the set point, but also allow regulation in real time, from a network architecture based on communication protocols such as Profibus or Ethernet [26], [27].

Therefore, this article aims to describe the automation of a concentric tube heat exchanger, for monitoring and data acquisition through SCADA, for which initially the control logic for data acquisition and processing is described through the Arduino controller. Then the integration with the Siemens 1214C programmable logic controller is described. Which allows the development of the regulation stage of the controlled variable through the SCADA data acquisition, supervision and control system.

2. LITERARY REVIEW

There are various studies in relation to the proposed solution described in this article, the same ones that justify its viability; In this regard, [28] shows satisfactory results regarding the implementation of an automated control system of a heat exchanger through a programmable logic controller (PLC), whose communication architecture was developed through a SCADA system, under Modbus communication protocol, managing to monitor and self-regulate the temperature in the exchanger. Likewise, other studies such as in [29] show an automated system that allows controlling the temperatures in a heat exchanger through PID-type control strategies (proportional, integrative and derivative) and techniques used regarding controllers tuning, with the which achieved the thermal transfer between the fluids, which were located at points with different temperatures in this concentric tube exchanger. The use of PID controllers, they are implemented many times through programmable logic controllers, in [30] the feasibility of automating concentric tube heat exchangers is highlighted making use of fuzzy PID control implemented on PLC, the same that allows to optimize the behavior and temperature regulation.

Castañeda *et al.* [31] the satisfactory results of the implementation of a control and automation system are shown making use of temperature sensors and flow meters built through Arduino controllers and interconnected to a programmable logic controller (PLC), on a heat exchanger. hot; it was possible to demonstrate the effectiveness of temperature control. Sánchez *et al.* [32] it is described that it was possible to develop a neural network algorithm from the acquisition of data through a SCADA system from a heat exchanger system, evidence that the monitoring allowed to obtain the data permanently by monitoring the variables of the process (temperature), achieving a high performance of the neural network. In the same line of research [33] shows a predictive maintenance model is developed, which guarantees the optimal operation

of a refrigeration system and temperature exchange in the process, from the integration of a SCADA system with sensors implemented through Arduino.

Fareeza *et al.* [34] the author points out that generating information through supervision and monitoring systems of an industrial process guarantees the flexibility of the system, since from these data the presence of some anomalies or failures can be foreseen as part of the process of some kind of disturbance, which will allow the parameters inherent to the industrial process to be corrected opportunely. In this regard. In Suryadarma and Ai [35] it is stated that the automation of industrial processes based on programmable logic controllers of the Simenes 300 family, guarantees the processing of digital and analog signals, allowing their coupling to monitoring and supervision systems, achieving relevant improvements in relevant aspects and significant as the precision and minimization of dead times.

3. DESCRIPTION AND DEVELOPMENT

3.1. Description

It should be noted that the research was carried out using the Edibom brand concentric tube heat exchanger module as a plant or process under study, and as part of my design I integrated six temperature sensors and two level sensors through Arduino controllers. Nano coupled to a MAX675 converter module. From the data acquisition through the sensors, these signals were transmitted for processing to a programmable logic controller, which based on the signals to be manipulated the sizing of the PLC was determined, the controller being the Siemens 1214C model, which contains analog inputs and outputs. In addition to controlling the level of the temperatures of the fluids inside the heat exchanger, their supervision and monitoring were also sought through the SCADA system, developed on an human machine interface (HMI) interface of the Siemens KTP 400 brand. Between the PLC and the HMI interface, they will be carried out through the Ethernet communication protocol. In Figure 1, the connection architecture used to achieve the automation of the concentric tube heat exchanger module is shown; as well as supervision and monitoring. One aspect to highlight is that this proposed solution uses as a temperature regulating element a system formed by a water tank, with level sensors also implemented with an Arduino nano controller, validated through research [36] they are used to achieve the temperature balance of the internal flows to the heat exchanger.

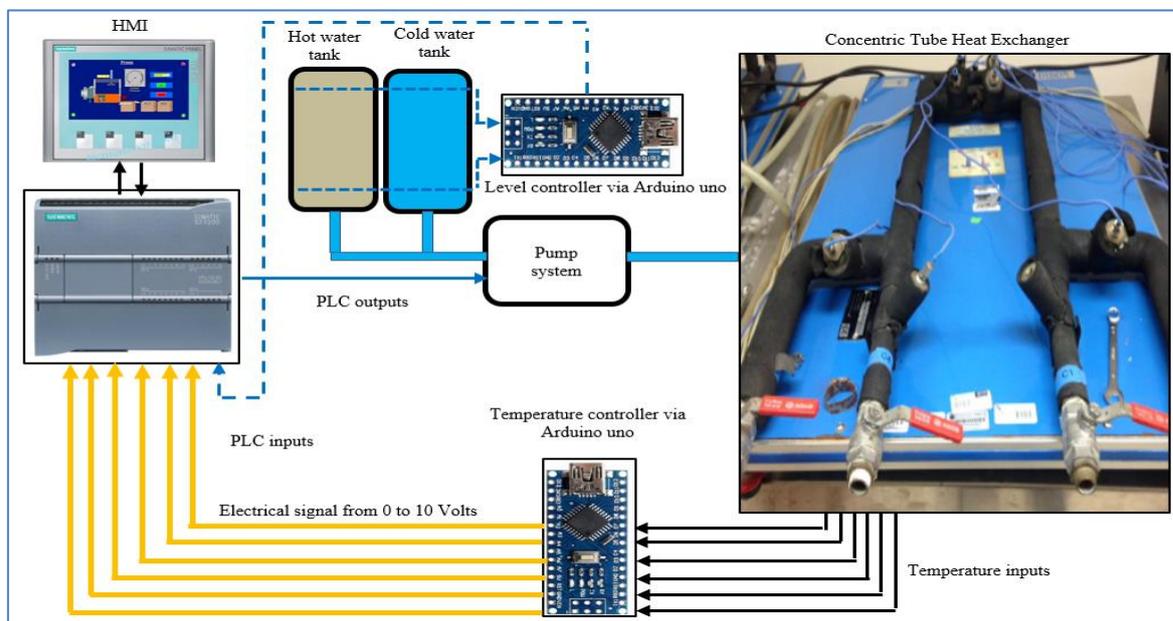


Figure 1. Edibom brand heat exchanger module located in the UNTELS laboratory

In relation to the temperature sensor implemented by means of an Arduino nano controller, Figure 2 shows its connection architecture as well as the logic that integrates each of the devices that will allow the acquisition and capture of the temperature of the flows in the six different one's points inside the heat exchanger. The temperature transducer is made up of 3 electronic components, which are, the temperature

sensor, the MAX6675 converter module and an Arduino Nano controller. The controller has a pulse width modulation (PWM) output signal with a range of 0 to 5 V (volts), then we will amplify it with an integrated TL081CP so that the signal from the PWM converts it to a voltage range of 0 to 10 V, in order for it to be transmitted to the analog inputs of the PLC.

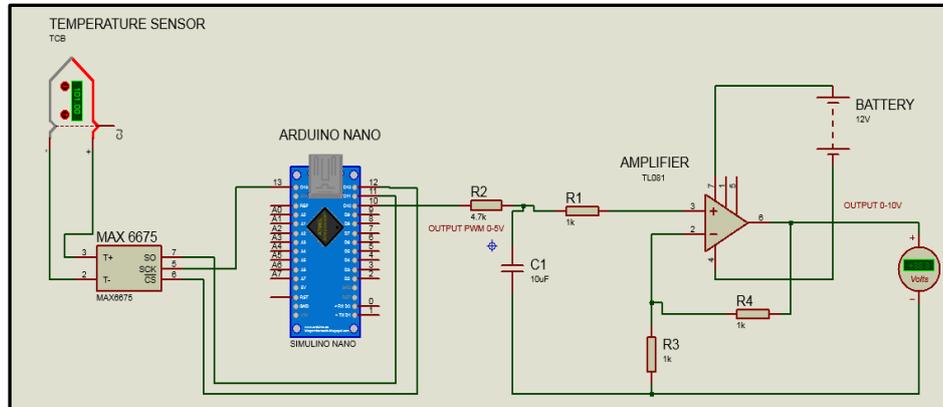


Figure 2. Temperature sensor architecture using Arduino Uno and MAX6675 converter module

Regarding the Arduino uno controller programming, 4 analog input type variables were initially declared, "int" linked to input 9 of the Arduino controller, ktcSO (input 11), ktcCS (input 12) and ktcCS (input 13). As well as 2 floating variables which will perform the respective calculations in the programming: temperature and output. With the setup function, Serial.begin (9600) was declared, as well as with the loop function, Serial.print ("C =") was declared, which writes the temperature in degrees Celsius.

In Figure 3, the programming carried out on the Arduino nano controller is shown. The Serial.println (ktc.readCelsius ()) this serial calls the variables ktc (ktcSO (input 11), ktcCS (input 12), ktcCS (input 13)) of the MAX6675 converter module and that they can work in degrees Celsius (they must to readCelsius ()). The formula for the work of the temperature sensor is: $\text{temperature} = \text{ktc.readCelsius}()$, after the temperature variable is registered in the ktc variable in Celsius it goes to $\text{output} = \text{temperature} * 2.5$. With this, the value of the output variable is obtained as a result of the product of the temperature variable by constant, this value of the contrast is obtained from the scaling process for its modulation by PWM pulse width from 0 to 5 volts to scaling in the range 0 to 255 (8 bits) of the Arduino. Regarding the programming of the programmable logic controller, initially the input and output elements involved in the plant and process (concentric tube heat exchanger) were identified, assigning each input and output a PLC address; These addresses are of type as floating word (W), double word (DW), as well as discrete signals (% I or % Q).

```

temperature_sensor
#include "max6675.h"
float temperature;
float output;
int analog = 9;
int ktcSO = 11;
int ktcCS = 12;
int ktcCLK = 13;
MAX6675 ktc (ktcCLK, ktcCS, ktcSO);
void setup() {
  Serial.begin(9600);
  delay (500);
}

void loop() {
  Serial.print ("C=");
  Serial.println(ktc.readCelsius());
  temperature=ktc.readCelsius();
  output=temperature*2.5;
  analogWrite(analog, output);
  delay(500);
}

```

Figure 3. Arduino nano controller programming segment

3.2. Development

We will start the description of the development, showing the programming carried out in the Siemens 1214C PLC programmable logic controller, for which the TIA PORTAL programming language was used. Figure 4 shows the programming of the actuators that will allow the temperature regulation in the heat exchanger. The actuators are linked to the level sensors of a hot and cold water tank, which from the control of the circulating flow input on the heat exchanger will balance the temperatures, it is then that it is important to guarantee the adequate water level in the tank.

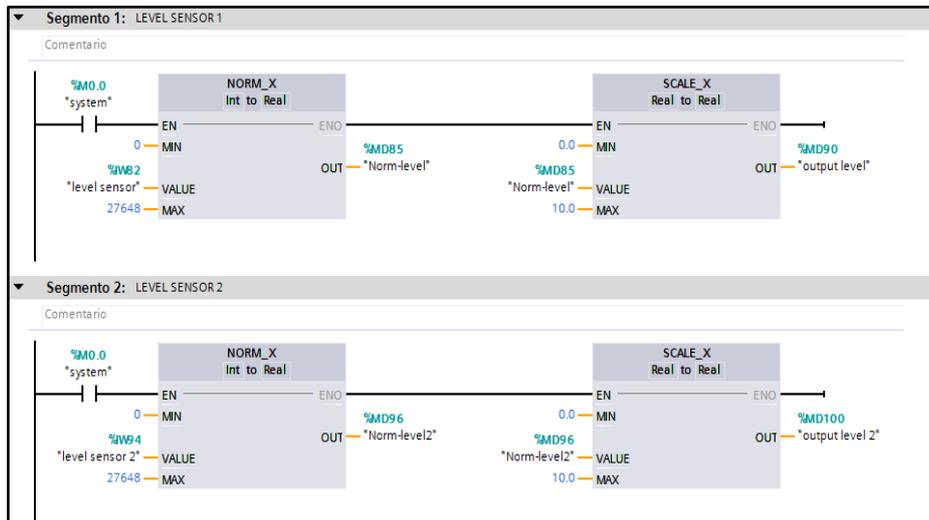


Figure 4. PLC programming segment for temperature level control

Level 1 sensor (% IW82) has to be normalized with digitization 0-27648 and has the Norm-level output (% MD85), then this output is scaled from 0 to 10 L and has an output (% MD90); this sensor is attached to the hot water tank. Level 2 sensor (% IW94) has to be normalized with digitization 0-27648 and has the Norm-level output (% MD96), then this output is scaled from 0 to 10 L and has an output (% MD100). This sensor is attached to the cold water tank. Regarding the actuation of the pump system, in Figure 5, the programming segment is shown, in which the start button (% I0.1) turns on the system mark (% M0.0), so that it then turns on the pump 1 (% Q0.3) and pump 2 (% Q0.4). The output level sensor 1 (output level-% MD90) turns off pump 1 (% Q0.3) through a comparator with a range lower than 1. The output level sensor 2 (output level 2-% MD100) turns off pump 2 (% Q0.4) using a comparator with a range less than 1.

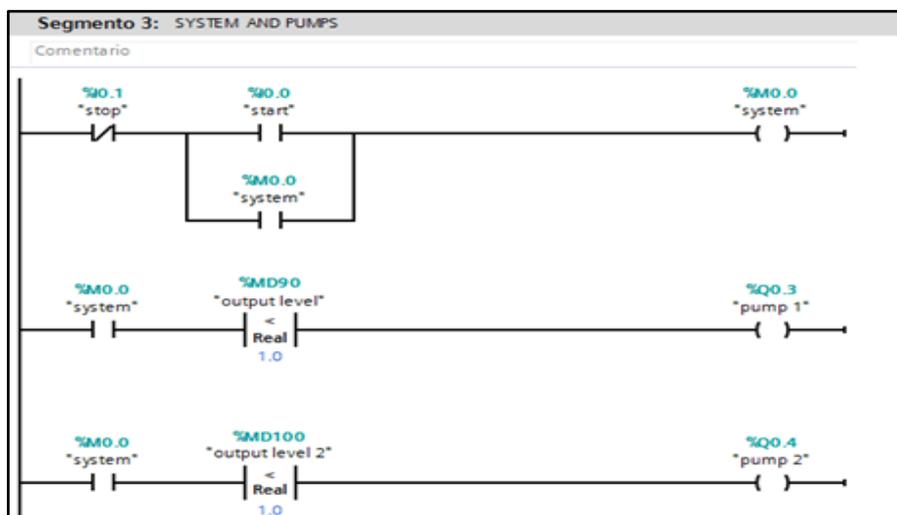


Figure 5. PLC programming segment for pump system control

With regard to temperature sensors, it is shown in Figure 6, that the hot temperature sensor 1 (%IW0) is normalized with digitization 0-27648 and has the output Norm-temperature-hot (Norm-temperature-hot 1-%MD2), then this output is scaled from 0 at 100 °C and has a hot temperature output (output temperature - hot 1-%MD6). This sensor is coupled in the pipeline as shown on the HMI with the name Tsh1. Regarding the hot temperature sensor 2 (%IW11) it has to be normalized with the digitization 0-27648 and it has the Norm-temperature-hot output (Norm-temperature-hot 2-%MD26), then this output is scaled from 0 to 100 °C and has a hot temperature output (output temperature - hot 1-%MD54). This sensor is attached to the pipeline as shown on the HMI under the name Tsh2. Finally, in the programming it is shown that the hot temperature sensor 3 (%IW14) has to be normalized with the digitization 0-27648 and has the Norm-temperature-hot output (Norm-temperature-hot 3-%MD30), then this the output is scaled from 0 to 100 °C and has a hot temperature output (output temperature - hot 1-%MD58). This sensor is coupled in the pipeline as shown in the HMI with the name of Tsh3.

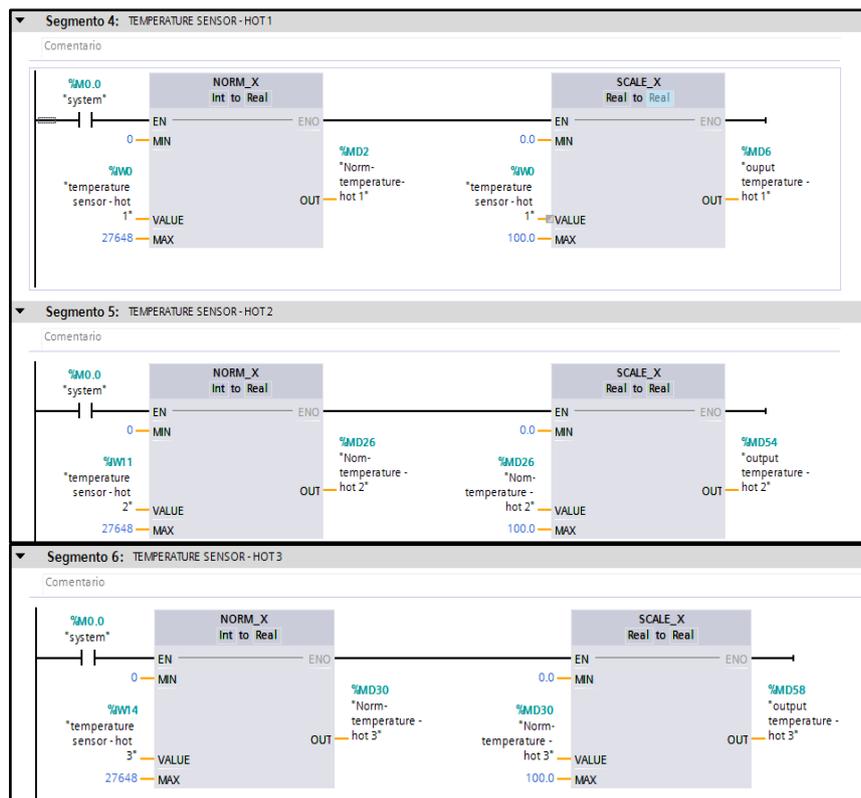


Figure 6. PLC programming segment for control of hot water sensors

4. RESULTS AND DISCUSSION

4.1. Results

After the implementation of the control and automation system on the heat exchanger, the data acquisition was carried out through the SCADA system. Through the implementation, it was possible to demonstrate the viability of integration between technologies, since Arduino nano controllers were used for the level and temperature sensors, while for the control of the actuators, with which the desired temperatures are achieved in each location of the heat exchanger, the Siemens 1214C PLC was used; In addition, the communication interface that allowed the supervision and acquisition of data in an optimal way is Ethernet. In Figure 7 it is shown in the HMI interface, that when the hot water tank shows 9.2 liters and the cold water tank in the same way, in the pipe in which hot water circulates, optimal values are obtained in the sensors. Thus, the hot temperature sensor (Tsh) shows the values Tsh 1 equal to 70.5, while Tsh2 shows a value of 50.1 and finally Tsh3 shows a value of 25.2; thus it is also evidenced that the values are decreasing due to the water circulating in the other pipe. In the pipe in which cold water circulates, it shows the values of the cold temperature sensors (Tsc), it shows the values of 5.2, 10.4 and 14.6 for Tsc 1, Tsc2 and Tsc3, respectively. This change experienced by the hot water pipe is due to a heat transfer with respect to the cold water pipe.

As well as evidence of the multiple results that were achieved, in Figure 8, in the HMI interface, it is possible to show that the tanks containing hot and cold water reduce their volume to 3.1 liters; This is due to the fact that the hot temperature sensors (Tsh) show the values Tsh 1 equal to 71.2, Tsh2 equal to 42.1 and Tsh3 equal to 22.5. Finally, in relation to the previous results, the cold water sensors (Tsc) show the values Tsc 1 equal to 5.1, Tsc2 equal to 11.1 and Tsc3 equal to 15.

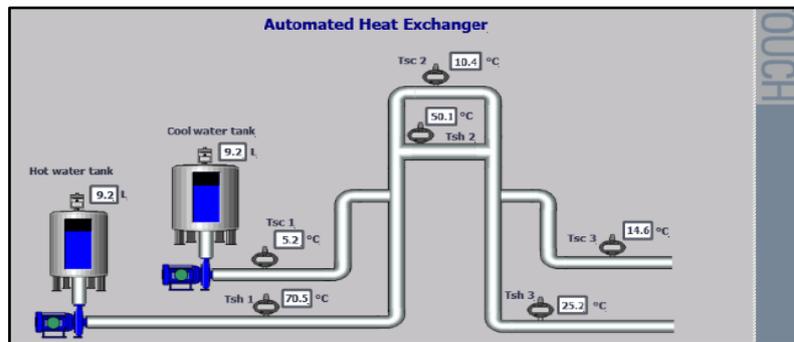


Figure 7. Results obtained from the heat exchanger data acquisition and supervision system

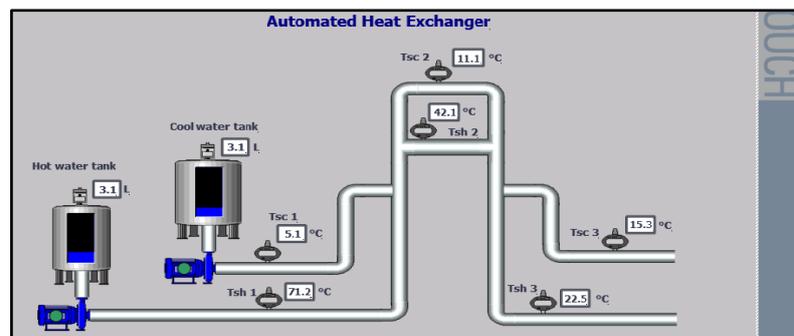


Figure 8. Results of the data acquisition system for Tsh 1 = 71.2, Tsh2 = 42.1 and Tsh3 = 22.5

4.2. Discussion

In relation to the temperature sensor implemented by means of an Arduino nano controller, it is shown that its connection architecture as well as the integration logic used for the acquisition and capture of the temperature of the flows in the six different points within the heat exchanger, turned out to work in a correct way; It is necessary to point out the pre-processing and conditioning of the signal was carried out by means of the PWM output signal with a range of 0 to 5 V, with which after its amplification through the integrated TL081CP it was possible to convert to a voltage range of 0 at 10V, with which it could be integrated and transmitted to the analog inputs of the PLC. In this regard [28], indicates that in the search for an interface that allows the coupling of temperature sensors and transducers in the concentric tube heat exchanger, satisfactory results were obtained using a closed loop circuit and pulse width modulation (PWM), for which it supports the result obtained in this investigation. With respect to the use of a Siemes 1214C programmable logic controller, it allowed the control of actuators and sensors, guaranteeing the regulation and control of temperatures in the heat exchanger; In this regard, in [29] and [30], although they manage to perform temperature control in a heat exchanger of the same type, they mention that they do it using PID controllers; Rather than disagree regarding the type of approach used, from my perspective our proposals are not far from this because the Siemens 1214C programmable controller has a PID function block, which can also be used as a contingency or parallel alternative; However, the contribution is that it is being shown that both architectures are valid for the control of a heat exchanger. In relation to the acquisition and monitoring of data through the HMI interface, it was possible to perform the acquisition and monitoring of data in an optimal way; In this regard, in [33] he refers to the use of an HMI interface, specifying that it is convenient from the point of view of the historical record of alterations of the temperature variable under study, that this interface contains both graphic and numerical components; In this regard, we agree on this type of approach

since what is sought through this interface is to have a representation of the behavior of the system, it will not necessarily be located in places close to the plant or process, so many times the HMI interface It is found in places distant from the process, so it must be strictly used to show information through graphics and its variations in real time.

5. CONCLUSION

It is concluded that it was possible to automate the concentric tube heat exchanger, for monitoring and data acquisition through SCADA, integrating Arduino uno controller architectures and Siemens 1214C programmable logic controller. Allowing to achieve the regulation of the temperatures of the fluids that run through the concentric tubes of the heat exchanger, showing through its HMI system, the representation in real time of the temperature values, as well as the variation of the filling levels in the tank system, whose signal conditioning was carried out by means of the PWM output signal with a range of 0 to 5 V, with which, after amplification through the integrated TL081CP, it was possible to convert to a voltage range of 0 to 10V, with which it could be integrated and transmitted to the analog inputs of the PLC. From the different experimental tests, it was possible to determine that the flow is directly proportional to the drop or difference in temperature in the hot fluid, and inversely proportional to the increase in temperature in the cold fluid, managing to verify the effectiveness of the heat exchanger.

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