INGE CUC, vol. 11 no. 1, pp 85-98, January - June, 2015

SCADA System of Physicochemical Variables in a Mixture Separator*

Sistema Scada de Variables Físico-Quimicas en un Separador de Mezclas

DOI:http://dx.doi.org/10.17981/ingecuc.11.1.2015.09

Research Article - Reception Date: September 2, 2014 - Acceptance Date: December 17, 2014

Claudia Marcela Bustamante Álvarez
Electronic Engineer, Universidad de los Llanos. Villavicencio (Colombia). marcela.bustamante.a@gmail.com.co

Javier Eduardo Martinez Baquero
Master in Educational Technology, Universidad de los Llanos. Villavicencio (Colombia). jmartinez@unillanos.edu.co

Camilo Torres Gómez
Electronic Instrumentation Specialist, Universidad de los Llanos. Villavicencio (Colombia). camilo.torres@unillanos.edu.co

To cite this paper:
C. M. Bustamante Álvarez, J. E. Martinez Baquero and C. Torres Gómez, “SCADA System of Physicochemical Variables in a Mixture Separator” *INGE CUC*, vol. 11, no. 1, pp. 85-98, 2015.DOI: http://dx.doi.org/10.17981/ingecuc.11.1.2015.09

Abstract--- This paper presents the results of a research project developed by professors from Universidad de los Llanos and Colciencias Young Researcher, whose aim is to implement the necessary instrumentation to monitor and control with a SCADA system of physicochemical variables for a mixture separation process in oily water, thereby seeking to minimize environmental damage in water sources. The project was divided into three methodological stages: the establishment of interest variables, the design and implementation of the SCADA system, and the testing for results validation. This system has sensors to capture and transfer data to a PLC (S71200) for each of the system variables such as temperature, level, flow and pH. It also has HMI interface for interacting with the system. The SCADA system greatly facilitates process monitoring and establishes the possibility of remote action, just by providing the programmable logic controller (PLC) to an Ethernet network.

Keywords---- Automation, Controller, Instrumentation, Human Machine Interface (HMI), Mixtures Separator, SCADA

Resumen— Este artículo presenta resultados de proyecto de investigación desarrollado por docentes de la Universidad de los Llanos y joven investigador Colciencias, cuyo objetivo es implementar instrumentación para supervisión y control de sistema SCADA de variables físico–químicas en proceso de separación de mezclas en aguas oleosas, buscando minimizar daños ambientales en fuentes hídricas. El proyecto se dividió en tres etapas metodológicas, se establecieron variables de interés, se diseñó e implementó el SCADA y se validaron resultados mediante pruebas. Este sistema dispone de sensores para capturar datos transfiriéndolos a PLC (S71200), correspondiente a cada una de las variables del sistema como son temperatura, nivel, caudal y pH, además dispone de interfaz HMI que permite interactuar con el sistema. El sistema SCADA facilita en gran medida la supervisión de procesos, establece la posibilidad de acción de forma remota, tan solo basta con proveer el dispositivo lógico programable (PLC) a una red Ethernet.

Palabras claves-- Automatización, Controlador, Instrumentación, Interfaz Hombre Máquina (HMI), Separador de Mezclas, SCADA

---

[*] Article derived from the research project entitled “Design and implementation of a supervision and control system of physicochemical variables in a mixture separator”. Funded by University de los Llanos, and Colciencias. Starting date: March 22, 2013. End date: March 21, 2014.

I. Introduction

Today, there are various factors that significantly affect the environment due to lack of awareness of people, especially those involved in processes that affect pollution. One of the problems with more negative effects is the contamination of water tributaries through the dumping of wastewater without any treatment, such as discharges which are made into public sewers, a product of commercial activities, specifically car washers, gas stations and car service shops.

Currently, there is great concern about environmental problems that are occurring and the risks they entail, that is why government agencies have strengthened the corresponding legal framework.

The monitoring and supervision of processes in different parts of the industrial plants is characterized by difficulties in making measurements or the continuous need for monitoring data. This is the reason for the design of a SCADA system, which is software that enables real-time feedback through field devices (sensors and actuators) and a PC or HMI screen, using communication tools so that different remote stations can be monitored and even commanded. In addition, databases and historical reports are generated to schedule maintenance of equipment.

One aspect to consider in the present investigation has to do with the work and projects in this field. It is worth mentioning that worldwide there are companies that sell various types of separators at an industrial level, among which are countries like the United States, Chile, Ecuador and Argentina. In Mexico, where there have been studies that seek to find new methods of separation, a prototype to treat wastewater from car wash business was recently presented by researchers from the Division of Basic Sciences and Engineering of Universidad Autónoma de México (UAM) and the Graduate School of Ecatepec. It is important to note that this development was based on the method of separation and that it has no automation involved that allows the application of instrumentation with which to measure various parameters, and also lacks monitoring systems unlike our proposal research that does include those systems.

In the industrial context, the SCADA system covers a wide range of applications and has been well received, for example, in the industrial area of oil and gas, it rose by 9.3% in the last four years, this is because telecommunication technologies have advanced significantly in the last decade, encouraging the development of such a system.

In Spain, at the beginning of January 2013, a new version of the Supervisory Control and Data Acquisition system (SCADA) from the electric power distribution network Electra Caldense was put into service, with the aim of improving its management and operation. This new version allows the power grid control to apply new ways of communicating with greater capacity, reliability and speed, such as optical fiber and Wi-Fi technology. In addition, more precise electronic control relays are used in case a fault occurs in the power grid, so that the fault location can be known in real time and isolated as soon as possible in order that it affects the fewest customers and for the shortest possible time. It also has a version to be used with smart phones to increase the possibilities of visualization and control of the power grid status.

SCADA systems in Latin America have also had applications in the field of energy supply. A great example is the neighboring country Panama whose energy company has, since 2001, a SCADA system that is used to monitor and control the generation and transmission of electric supply at a national and international level, as well as to minimize the economic costs of energy production, accounting and information management within the wholesale Electricity Market of Panama's electrical activities.

The implementation of SCADA systems has also been evident in Colombian industry; a great example is the company Pacific Rubiales Energy Corp., which is responsible for the exploitation of oil in Rubiales area located in Meta department. For oil exploration activity, the company launched a SCADA system that integrates information from 265 oil wells, where the company gets a countless number of data ranging from the reservoir to the oil transfer lines. The implementation of this system contributed to an increase in production, which went from 14,000 barrels to 200,000 barrels per day.

For this reason, the application of technology in industrial processes can help achieve a reduction in the environmental impact, for example, with the implementing of the mixtures separating equipment, it is possible to mitigate water pollution in water tributaries, as it recovers about 95% of water, which can be reused or dispose without polluting risks. The efficiency is obtained from the measurement of the level sensors located in the storage containers.

For this purpose, this article describes the development of a research project carried out at the facilities of Universidad de los Llanos where a SCADA system for industrial variables is implemented with which it is accomplished an interesting analysis on the separation process of oily water through a mixtures separator, highlighting the great contribution involved in process automation.

It is important to clarify that this work is the first to be developed in the region of the eastern plains (Llanos Orientales, Colombia), which gives our project greater importance since it will be a pioneering effort in this area of development.

In the next section, the concepts related to the SCADA system are clarified.

II. Theoretical Framework

A. Automation

The dictionary of the Royal Spanish Academy defines *automation* as the discipline that deals with methods and procedures aimed at replacing the human operator for artificial operator in the execution of a physical or mental task previously programmed [1].

In recent years the *automation* concept, defined as the application of automation to the control of industrial processes, has been evolving rapidly due to the fact that automation allows the improvement of operations of a production process; in addition to the quality of produced goods, it ensures the companies the achievement of their objectives with optimum performance.

Automation in the industry, until the 70s, were executed exclusively with relays, using what is known as a wired logic, but from these years, the automation systems (PLCs) disrupted that path and moved to programmed logic.

The first versions and models of PLCs were expensive, difficult to program, they had relatively little memory and almost no peripherals. Already in the 80s, they improved both in price and performance, but programming was still difficult to perform, which meant that only a small group of specialists were trained for its installation and maintenance [2].

The development of different technologies (mechanical, electrical, chemical, etc.) over the first half of the twentieth century led to a gradual rise in the complexity of systems and produces many physical variables that had to be monitored and controlled. But such control cannot be performed directly by humans, because humans lack sufficient capacity to act through their hands, sensitivity and responsiveness to stimuli that their senses get.

Therefore, it was proposed the development of equipment capable of processing and storing physical variables that constitute information processing systems. In fact, the need for these systems goes back to the early stages of development of science and technology, but it was the discovery of electricity and its subsequent technological dominance through electronics, which allowed the development of systems that store and process information through electrical signals with a very small energy consumption allowing to gradually reduce its size and cost. These systems receive the generic name of "electronics," that consequently, make them able to receive information from other external systems which in turn can be divided into two main classes:

1. Industrial products: systems that perform a particular function, such as a washing machine, a TV, a drill, etc.
2. The industrial processes: defined as a set of actions carried out by one or more machines properly coordinated to allow the manufacture of a product. Examples of industrial processes: a car assembly or a beverage factory.

Still, most of the physical variables to be measured are not electrical. Among these are: temperature; pressure; the level of a liquid or a solid; strength; light radiation; position, velocity, acceleration or displacement of an object, etc. Therefore, the coupling (interface) between the electronics and the production process must be done through devices called sensors that convert non-electrical variables into electrical [3].

An automated system is made up of elements or instruments, which are used for measuring physical variables, exercise control actions and transmit signals. In all processes, it is absolutely necessary to control and maintain constant some magnitudes [4].

In recent years, technology has introduced variations in the design of separators which lead to the increase in the capacity of units, while the equipment size and weight is reduced. To design separators is necessary to take into account the different states that can meet fluids and the effect the different physical forces have upon them [5].

The advancement of these technologies seeks to solve problems in society. In this specific case, it is sought to provide better management to wastewater coming from facilities as car wash services, which are the source of contamination of water tributaries of the city.

B. Industrial Instrumentation

Measuring instruments used industrially are primordial part within a system focused on controlling an industrial process. Good knowledge of instrumentation results in its adequate specification and selection for an industrial process, which in turn, will help as a factor of increasing quality and efficiency in production [6].

C. SCADA and HMI

SCADA comes from the acronym for Supervisory Control and Data Acquisition. It is a software application for production control that communicates with field devices controlling the process automatically from the computer screen. It also provides process information for various users: operators, quality control supervisors, etc.

The interface systems between user and equipment based on control panels full of control indicators, switches and measuring instruments are being replaced by digital systems that implement the panel on the screen of a computer or touch screen. Direct control is performed by digital autonomous controllers and / or PLCs that are connected to a computer that performs the functions of dialogue with the operator [7].

D. Controllers

In a process control of physicochemical variables, some variables such as temperature, pressure, flow and liquid level in a tank are crucial to its operation, so it is necessary to maintain and regulate desired values so that stability and safety can be ensured. This is done by devices (controllers) designed to develop an action on deviations that are observed in the values of the given conditions; it requires the coupling mechanism of transmission-measurement (Sensor/Transmitter) of the process variable, which will be the source of information for corrective action together with another mechanism of regulatory action execution decided by the controller.

An automatic controller compares the actual value of the output of a plant with the reference input (desired value), determines the deflection and produces a control signal to reduce the deviation to zero or a small value. The way in which the automatic controller produces the control signal is called *control action* [8].

The controllers are elements that are added to the original system to improve its performance characteristics in order to meet the design specifications both transient and steady state.

The first way to modify the response characteristics of the systems is the gain setting (what would later be defined as *proportional* control). However, despite the fact that the increase in gain improves functioning in steady state, a poor transient response is produced and vice versa. Therefore, it is necessary to add elements to the simple gain variation, which leads to various types of controllers [9].

For *basic action* is meant that the controller amplifies, integrates or derives input information or develop a sum between some of these actions. Accordingly, the controllers that are usually included within a process are the ones called *proportional action* (P), *proportional - integral* (PI), *proportional - derivative* (PD) and *Proportional - Integral - Derivative* (PID). And for some situations a control named two positions controller (On / off) is justified.

Often design specifications are used to describe what the system should do and how. These specifications are unique to each individual application and often include specifications as relative stability, accuracy in steady state, transient response and frequency response characteristics [10].

As energy source almost all industrial controllers use electricity or fluid pressure such as air. Thus controllers are classified according to the type of energy they use in their operation, such as pneumatic, hydraulic or electronic. The type of controller to use must be decided based on the nature of the plant and operating conditions, including considerations such as safety, cost, availability, reliability, precision, weight and size.

To control an industrial process there is the availability of distributed control systems, computers for monitoring, or a combination of both, connected by appropriate interfaces. Although systems are designed for best results, or for process stability or for optimization, the final control element is still necessary to control the flow of a fluid.

In the final control elements is important that the end control element works stably and has a good performance [11].

E. Wastewater

Wastewater is the used water and solids that by any means are introduced into the sewers and transported via the sewage system.

In general, *domestic wastewaters* are the liquids from homes or residences, commercial buildings and institutions. *Municipal wastewater* is liquid waste transported by the sewer of a city or town and treated in a municipal treatment plant, and *industrial wastewater* refers to sewage discharges from manufacturing industries [12].

The development of the germ theory by Koch and Pasteur in the second half of the nineteenth century marked the beginning of a new era in the field of sanitation. Before these studies, no one had delved too much into the relationship between pollution and pollutants. Snow in 1849 demonstrated the transmission of cholera through water that had been contaminated with sewage water; from that moment people became aware of the transmission of diseases through wastewater and identified this situation as a problem to solve.

Apart from pathogens, wastewater contains many other pollutants. To give a precise definition of wastewater is complex, since it depends on the characteristics of a certain location or industry, and also depends on the collection system employed. They could be:

- Domestic wastewater comes from residential or similar areas.
- Groundwater infiltration and uncontrolled contributions are waters that enter directly or indirectly in the sewer and whose composition is not known completely.
- Storm waters are waters resulting from surface washings with pollutants as heavy metals.
- Wastewater comes from industrial or hospital complexes.

The residential areas and shopping centers are the main sources of urban wastewater; therefore the amount of residual water depends directly on the amount of population that is why it is very typical to make a determination of the wastewater flow according to equivalent population [13].

III.Methodology

For the development of SCADA system, it was chosen a type of evolutionary methodology, divided into three stages, which are: analysis, design, implementation and testing. The methodology also allows returning to an earlier stage if any inconsistency or error is detected, or if any aspect of the system needs improvement.

It is worth mentioning that there is research whose general purpose is the design and validation of a data collection instrument and therefore all fieldwork phase consists in designing and validating the respective instrument. We must also recognize that the development of many investigations, already existing instruments are frequently used and, in many cases, they are already validated in similar contexts to the research to be performed; in these cases, it is recommended to use these instruments and, if necessary, make its corresponding adjustments [14].

The main objective of this project is the development of a SCADA system for visualization of the physical and chemical variables of a separator of oily water mixtures from a representation of an HMI using a PLC and by capturing the selected variables in the mixtures separator equipment.

The selected variables are *temperature, flow, level* and *pH. Level* is the most important variable because this variable sets the efficiency of separation in the equipment, comparing oil levels in the fluid inlet and the water and oil levels obtained on the outlet. The *flow* allows establishing the speed separation of the machine. The *pH* measured at the output stage allows establishing the conditions and the separated water and its dumping possibility into water sources or the need for additional treatment. Finally *temperature,* that even though it is displayed on the SCADA system for this project, it is not considered at this early stage, still it is contemplated for a second phase of the project: to establish its relationship with the separation efficiency.

The following is a description of the stages developed in the research project:

A. Separator Recognition

Initially, for the implementation of the instrumentation, it was necessary to know the functioning of the mixtures separator. It starts with the entry of fluid from the storage 250 L tank to the first compartment process structure; then, the fluid passes through corrugated plates, in which due to the density difference, oily substances are separated from water, these oily substances tend to rise forming a floating layer on the surface. After the liquid reaches a set level, a cylindrical filter having circular and motion generated by a motor must be activated. This filter would be in charge of collecting the oil that is on the surface and retrieve it via the outlet that has been assigned. The water that passes through the plates is sent to the second compartment, and then the water passes to a third compartment where there is the outlet to the collection tank. The constructed separator equipment is shown in Fig. 1.

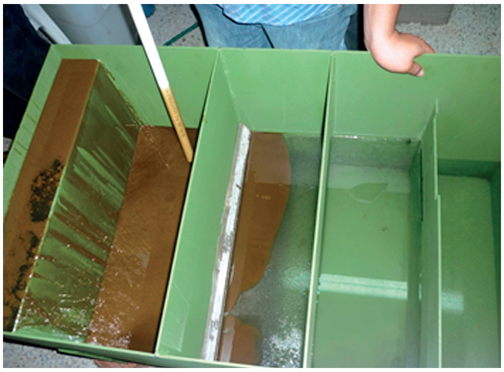


Fig 1. CPI Separator equipment.
Source: Authors

In addition to the separator structure, it has a storage tank 250 L, located at a height of 1.20 m, which stores the oily fluid to be directed towards the separator device through a pipe in PVC -1”. Also it has a 20 liter container that stores the recovered oil and a 250 L tank which stores the water recovered from the process.

Table I shows the results of the test separator.

Table I. Test Data Separator

Fluid	Filling Total Time	Flow Calculation
Water	22 Min	151.51ml / S
Water - Oíl	22 Min	151.51ml / S

Source: Authors

B. Selection and Installation of Instrumentation

After the analysis of the operation of the mixtures separator equipment, the next step is the selection and installation of the necessary instrumentation.

First the variables relevant to the process were determined: temperature, pH, flow rate; and level which is the most relevant variable because it allows establishing a measure to assess the recovery rate of oil and water, in order to assess the ultimate aim of the project.

The instrumentation was selected by analyzing the system requirements and after evaluating various alternatives offered in the market. With regard to temperature, it was decided to use an RTD (PT 100) sensor, as they can easily deliver accuracies to the tenth of a degree, with the advantage that the PT100 does not gradually stops running giving erroneous readings but normally opens up which allows the measuring device to detect the sensor failure to immediately give warning. Furthermore, PT100 can be installed at a distance from the meter without problem (up to 30 meters) using conventional copper cable for extension.

This sensor is located in the base of the main tank (see Fig. 2) and its function is to realize the continuous measurement of the oily fluid temperature to be sent to the process, wherein the display is also performed.

This sensor is easy to install and use, however, it requires an additional system to display the value of the signal. In this case, a *temperature controller* Autonics TZ4ST was selected, shown in Fig. 3. The sensor wires are connected to the back of the controller, and through simple programming established by the manufacturer's manual, it is possible to indicate the variable display in Celsius, as shown in Fig. 3. wherein the current temperature in the process is displayed: 28.1 °; in this way, the user has the possibility to know this variable in real time.

Fig. 2. Installed temperature sensor.
Source: Authors

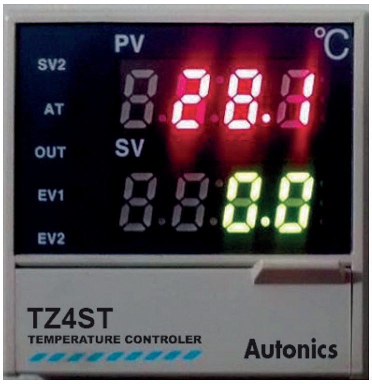


Fig. 3. Temperature Controller TZ4ST.
Source: Authors

As an important aspect of this temperature controller, there exists the possibility of implementing a PID controller via the programming provided by the manufacturer on the front panel, thus, for the second stage of the research project, it will be carried out the design of PID controller, according to the constants that are highlighted in (1) using the Ziegler Nichols Tuning rules.

$$PID = \text{Kp} + \frac{Ki}{S} + \text{KdS} \qquad (1)$$

These constants are listed in Table II and are obtained from design process, performed by the first method that the rules indicate.

Table II. Pid Controllers Tuning

Type	Kp	Ti	Td
P	T / L	INF	0
PI	0.9 (T / L)	L / 0.3	0
PID	1.2(T / L)	2L	0.5 L

Source: Authors

The temperature control system for the oil mixture is determined by the block diagram in Fig. 4 where the involved elements are shown, including RTD PT100 temperature sensor, placed in the feedback to set the system error, and thus, achieving the control of this variable.

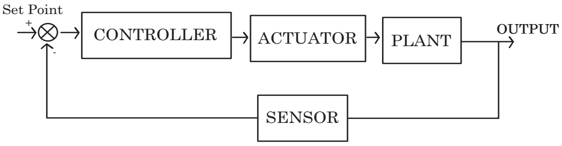


Fig. 4. PID controller.
Source: Authors

Moreover, the BL 931700 pH Mini Controller (see Fig. 5) which is an indicator and an installation panel controller was selected because it is designed for simplicity of use in a wide range of industrial applications. It has a range of 0-14 pH, with 0.01 pH resolution; a preset time control system, selection of dosing direction (Acid / Alk), contact for external control and disabling of dosing action. It also has a big display and 4-20 mA analog output. In this project it is only used as an indicator; control implementation is left aside for future work.

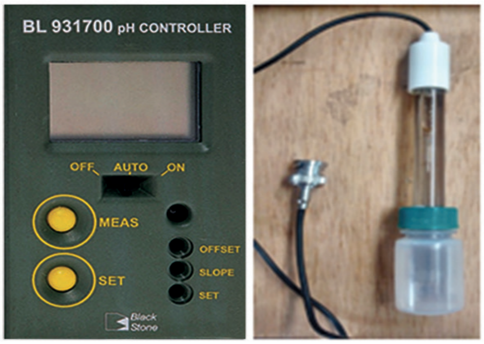


Fig. 5. Installed pH. indicator controller.
Source: Authors

This sensor is located in the recovered water tank, and the indicator in the control panel.

For flow measurement, the YF-S201 sensor has been selected (Fig 6) for its features: easy to use and reliability of the obtained measurement signal. This sensor has three wires: red (power 5-18V), black (ground) and yellow (output signal of the Hall Effect sensor)

This sensor is installed at the exit of the main storage tank, after the solenoid valve, at the inlet of the mixture separator equipment, and its function is to measure the outflow of the oil fluid, data with which an efficiency analysis of the separator equipment will be done.

Equation (2) is used for flow measurement:

$$Q = v \, . \, A \qquad (2)$$

Where:

Q: *Flow* (m^3/s)

v : *Speed* (m/s)

A = *Cross-sectional area* (m^2)

Fig. 6. Flow sensor YF - S201.
Source: Authors

The selected flow sensor provides a variable output frequency, for this reason the speed to be calculated based on the angular velocity sensor, as shown in (3):

$$v = w \, . r \qquad (3)$$

Where:

w = *angular speed*

In addition, this flow calculation can be verified by the Bernoulli equation of fluid mechanics (4)

$$\frac{P}{\gamma} + Z + \frac{V^2}{2g} = \frac{P}{\gamma} + Z + \frac{V^2}{2g} \qquad (4)$$

Where:

P_1 is the pressure on the surface of the main tank, which is zero for being at atmospheric pressure.

Z_1 is the level of the mixture with respect to the starting position.

V_1 is the velocity of the mixture in the tank surface, which is equal to zero to be quasi-static.

P_2 is the pressure in the exhaust pipe, which is zero for being at atmospheric pressure.

Z_2 is the output level of the mixture, which is taken as zero, for reference.

V_2 corresponds to the speed of the mixture.

Therefore, it is concluded (5):

$$V_2 = \sqrt{2 * g * Z_1} \qquad (5)$$

Now (6):

$$Q = \sqrt{2 * g * Z_1} * A \qquad (6)$$

Due to the fact that the processing to be carried out by the control board for calculating the flow was complex in terms of frequency, an additional step in which a conversion of frequency to voltage becomes necessary, which is achieved with the use of the LM2907 integrated circuit shown in Fig. 7.

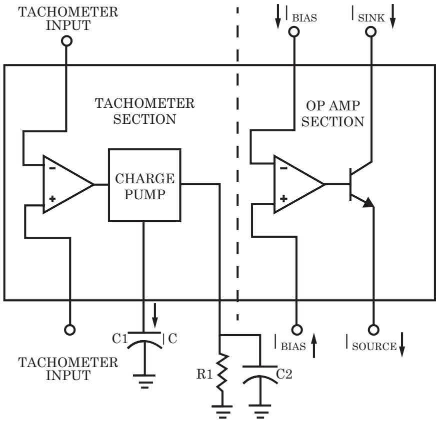


Fig. 7. Frequency to Voltage Conversion Circuit
Source: Texas Instruments

Equation (7) shows the conversion formula used:

$$Vo = Vcc \, .fin.C1.R1.K \qquad (7)$$

Where *K* is the typical gain constant = 1.0.

Regarding the level, it is measured at four points of the process. For this purpose, the ultrasonic level sensor SRF06 is selected (Fig. 8), which has a 4-20mA output signal. This sensor is easy to install, as it only has 2 connecting wires. However, it should be noted that this sensor only works with a voltage range of 9V to 24V. Likewise, because of the structure of this sensor, it was necessary to adequate a housing for installation.

Fig. 8. Installed level sensor.
Source: Authors

The installation of the four sensors is distributed as follows:

1. *In the main storage tank:* It measures the minimum level of the tank for the start of the process and the maximum level of the tank when filled to prevent leakage of fluid and sensor damage.
2. *In the mixtures separator equipment:* It measures the current level of fluid in the machine to activate the motor in charge of the oil collector and together with the level sensor from the main tank to send the signal and shut off this fluid coming from the main tank.
3. *In the oil collection tank:* It measures the amount of oil recovered.
4. *In the water collector tank:* It measures the amount of water recovered, and is located in a low tank of 250 L capacity.

With the values obtained by the sensors, the amount of recovered water and oil can be determined, thus, measuring the efficiency process.

To calculate the amount of substance in the containers it was applied (8) and (9), corresponding to the main storage tank (Fig. 9) and the oil collection tank (Fig. 10) respectively.

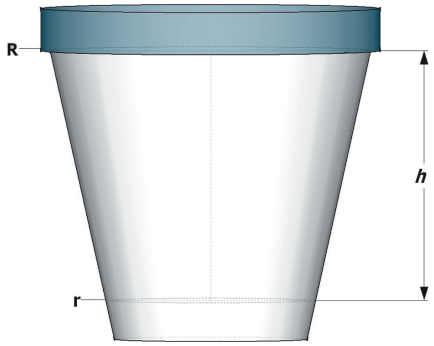


Fig. 9. Mixture container tank.
Source: Authors

$$V = \frac{1}{3}\pi.h(R^2 + r^2 + R + r) \qquad (8)$$

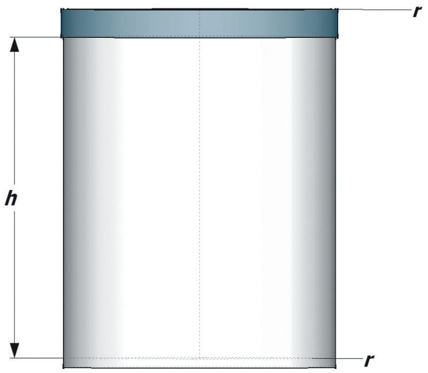


Fig. 10. Oil container tank.
Source: Authors

$$V = \pi.r^2.h \qquad (9)$$

C. Programmable Logic Controller

To perform system automation, the S7-1200 Programmable Logic Controller (PLC) was used as it offers flexibility and control over a variety of devices for different automation tasks. Thanks to the powerful instruction set it offers, it is suitable to control a wide variety of applications.

This controller is located on the control board, and its function is to receive signals from the sensors, processing them using the control program, make a decision and give a command to the final control elements. The system has two operating modes: *local mode* and *remote mode*. In the first, the process is performed when the user operates the buttons; in this mode the user has the option to enable or disable locally the final control elements according to need. In the second mode, the process control is performed by the HMI user interface computer implemented; in this mode the user also has the option to enable or disable remotely the final elements.

D. Final Control Elements

It was established that three valves were necessary (Fig. 11) for controlling the passage of fluids at different stages of the process. These solenoid valves are distributed as follows:

1. *Main Tank:* The solenoid valve is at the exit of the main tank and is responsible for allowing or not allowing the passage of oil or fluid from the main tank to the process tank.
2. *Oil collector container:* The solenoid valve is in the process tank at the exit of the oil extractor and is responsible for allowing the passage of recovered oil to the container where the oil will be collected.

3. *Water tank:* the solenoid valve is in the process tank at the last compartment and is responsible for allowing the passage of recovered water to the tank where it will be collected.

Fig. 11. Solenoid valves installed in the process.
Source: Authors

E. Operating System

As mentioned in previous pages, the research project shown here is a SCADA system, that through a laptop computer displays the chosen variables such as temperature, flow, level and pH of an oily fluid mixtures separator.

The system processing capacity is 200 liters, whose process mainly lies in separating oil-water fluid.

These variables involved in the process are captured by the mentioned sensors and are taken to the Siemens S7-1200 PLC and according to the data obtained in the process; the system determines the actions to take, such as opening of the main solenoid valve to start the process or opening of the solenoid valve to collect oil or water. In turn, using the RTD, a constant capture of the temperature of the main storage tank is obtained.

Fig. 12 shows the P&ID system diagram, where the elements involved in the process are seen clearly.

In addition, the SCADA system has an implemented control panel, from which the elements of the system can be accessed manually, not only start, and emergency stop buttons but also led indicators.

As can be seen, in the control panel (Fig. 13) the temperature controller, which also displays this variable, and the pH controller have been installed, being the pH controller, in this project, located as a viewer of this variable.

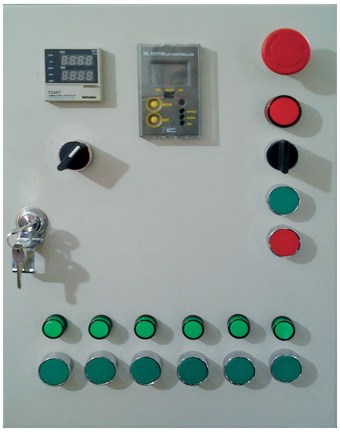


Fig. 13. Front view of the control panel.
Source: Authors

Fig. 14 shows the control panel inside with PLC and the digital source and the PCB board standing out.

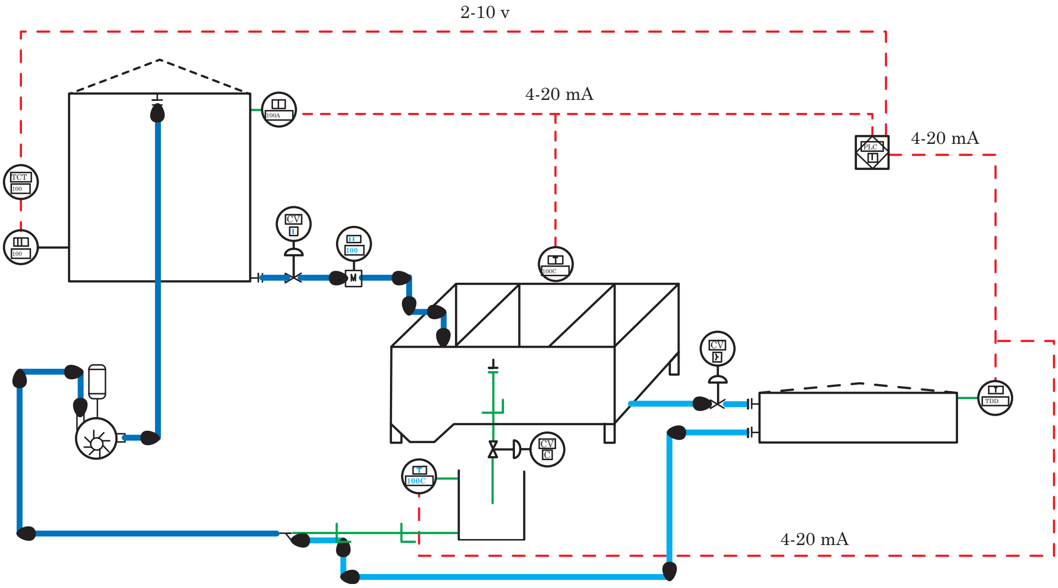


Fig. 12. P&ID diagram.
Source: Authors

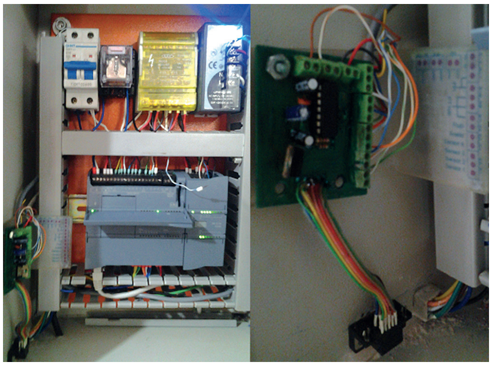


Fig. 14. Inside view of the control panel.
Source: Authors

IV. Results

Once the design and installation of the automated separator equipment is finished, the respective tests of the system are performed. For these tests, it is important to know that the maximum oil fluid that can be recovered is 200 liters; although the main storage tank has a capacity of 250 liters, a minimum operating level of 50 liters has been established.

The oily mixture present in the main storage tank is directed toward the mixture separator machine through a PVC pipe of 1 “ that allows the fluid to pass by the activation of the first 110V solenoid valve.

These first tests consisted of pouring water and oil in the separating machine in automatic mode for measuring separation times and quantities, mainly.

Some results are presented in Table III. As can be seen, the amount of applied oil varies in each test. A first analysis shows the amount of water recovered in each test, considering that the reference volume is 200 liters and the amount of oil does not exceed 10 liters, indicates that the separating equipment is able to extract a large percentage water of the oil mixture having an average of 189.4 liters.

Moreover, with regard to oil separation, it is possible to bring out from the results that the system permits removal of a high percentage of the oily mixture. As shown in Table III, the separating machine achieve low error percentages, such as in the 10 liters test, where 9.7 liters were separated out of 10 liters present in the oily mixture, i. e, an error of only 3 %; or what is noted in the evidence where 5 liters of oil were applied, where the error rate was an average of 5%, with a separation of 4.75 liters on average of the oily mixture.

Fig. 15 shows the system response with respect to the recovered oil, it can be seen that in the extent that the amount of applied oil is greater, the greater the recovered oil, achieving in this way a high efficiency of the mixture separator equipment, displayed on the linear response of the previous figure. In (10) its directly proportional behavior is shown.

$$y=0{,}9858-0{,}1725 \tag{10}$$

Additionally, the statistical correlation analysis establishes the dependence between these two variables, as shown in (11).

$$R^2=0{,}9998 \tag{11}$$

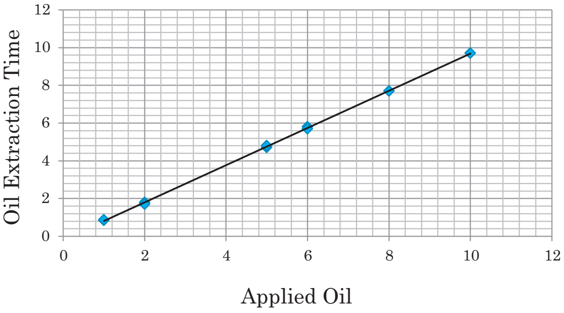


Fig. 15. Recovered Oil Result.
Source: Authors

Table III. Automated Equipment Testing

Separation Process Time (min)	Oil Extraction Time (min)	Recovered Water (litros)	Applied Oil (litros)	Recovered Oil (litros)	Oil Separation % Error	Unfiltered Water Ph	Filtered Water Ph
21.5	4	191	1	0,85	15%	8,89	7,91
22	4	190	1	0,87	13%	8,88	7,90
22	7,9	190	2	1,8	10%	8,50	8,01
23	7,8	191	2	1,7	15%	7,98	7,20
24	11	189	5	4,7	6%	7,47	6,57
23	11,5	190	5	4,8	4%	8,02	7,53
21	12	188	6	5,8	3,33%	7,78	6,98
22	13	189	6	5,7	5%	8,58	7,87
22	15	189	8	7,7	3,75%	8,58	7,87
22	15,2	189	8	7,7	3,75%	8,58	7,87
23	18	189	10	9,7	3%	3,33	7,55
21,5	18,6	188	10	9,7	3%	8,10	7,43

Source: Authors

Moreover, an important analysis has to do with the time of extraction of oil, measured as the elapsed time from the moment when the roller starts its operation at the presence of oil until it ends. As shown in Fig. 16, as the oil applied to the oil blend increases, the time it takes the system to achieve extracting said oil increases, leading to a directly proportional relationship (12).

$$y=1,4621x+3,7022 \qquad (12)$$

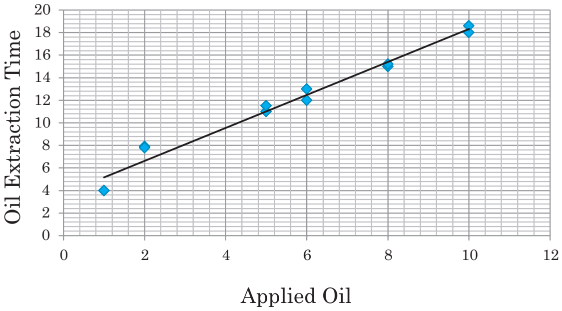


Fig. 16. Oil Recovery Time.
Source: Authors

Finally, from this analysis of this relationship shown in Fig. 16, it is concluded that the correlation is the one shown in (13), indicating a direct dependence between the variables under analysis.

$$R^2=0,9732 \qquad (13)$$

With respect to total process times, it is concluded that they are quite high; this is mainly because the system in general has a pipeline of only ½ ", therefore, the time it takes the recovered water to go out of the machine is equally high.

Initially, the pipe carrying the oily fluid from the main storage tank to the separating machine was also ½ ", but a delay was observed in the filling of the machine, for this reason, it was changed to 1" and time decreased approximately 50%. Thus, for a second phase of the project it has been decided to change all piping to 1 ".

Although times are quite high, it is verified that they are constant, since the difference between each test is low.

In relation to the error rates of oil extraction, significant results are achieved (Fig 17). As can be seen, in the first test the largest margin of error is obtained with oil, because that initial liter of oil is poured directly into the machine; from this point, oil is lost on the way in small quantities. First, a small portion of oil remains on the parallel plate grid, then another portion is lost in the exhaust roller, as there is no way to get all the oil out of it, and a fairly small percentage, gets through with recovered water. It should be noted that the purpose of the machine is not to get potable water, but water usable in processes beyond human consumption.

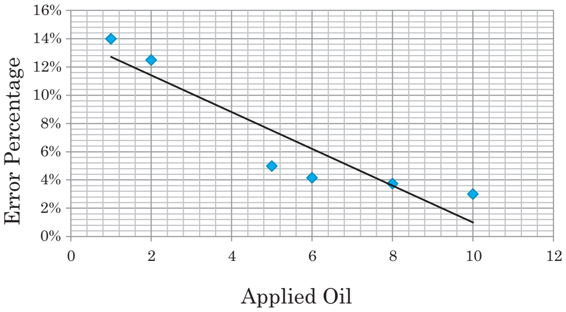


Fig. 17. Error rates of oil extraction.
Source: Authors

However, the graph shows that the higher the amount of oil applied in the oil mixture, the error rate decreases significantly, an inverse relationship, concluding that the system operates with less error if the oil amount is higher, as shown in (14).

$$y= -0,013x+0,1401 \qquad (14)$$

Finally, the correlation analysis shows the variable dependency (15).

$$R^2=0,8529 \qquad (15)$$

In the following tests the same procedure was performed but up to this point there already exists oil in all machine components, however, it is possible to verify that the recovered water is almost constant. Regarding the oil, it varies in each test; however, low error rates were achieved.

From this analysis we can conclude that despite the fact that the efficiency to recover the oil is not ideal, this does not affect the project desired results since the percentage of recovered water is quite high, this turns out to be the main objective of this process.

Moreover, with respect to the programming process, it is necessary to identify each of the outputs (actuators or pilots generally) and inputs (variables to measure and / or control).

These inputs and outputs are arranged as shown in Fig. 18, in which the necessary parameters are assigned to each variable for proper operation. These parameters are: name, data type and direction.

1. *Name:* it is simply the name that is assigned to a specific variable, either input or output.
2. *Data Type:* this parameter determines the type of variable that is being used, in other words, if it is referred to an on / off control, is said to be a Boolean variable, which has only one bit and whose only output options are "true" or "false", on the other hand, if a signal from a working sensor 4-20 mA needs to be captured, it is necessary to use a bigger data type, usually for this kind of sensors a data type "int" which has 16 bits is assigned.
3. *Address it* is the position within the PLC whether it be physical (input or output) or virtual (marks) that is assigned to a variable.

In addition to the inputs and outputs, there is another variable that can be stored, controlled or displayed on TIA Portal, these are "marks," which are variables whose main purpose is to store a value or serve as a replacement for a physical button that serves for controlling from an HMI.

Moreover, with respect to the S7-1200 PLC, which has an input module and analog or digital outputs, the input module receives 4-20 mA analog signals and 0-10 V voltage coming from application devices (sensors) to convert the signals into logic signals that can be used by the CPU.

The CPU makes decisions and executes control actions based on the instruction program (control program) that is in the PLC memory. Output modules convert the control instructions from the CPU into analog or digital signals that can be used by different actuators (solenoid valves, motors, etc.). The software can be divided into six main phases shown in Fig. 19.

Thus, after completing the tests, the proper functioning of the programming was verified. Similarly, the sensors send the information properly, which in turn is processed in the PLC with which the display is set to a laptop computer that has the HMI software (Human machine interface); from there operating instructions such as: activation or stop the process execution, activation or closing valves, and motor on or off can be given. Also the supervision of the variables measured by the sensors and the tanks level display can be monitored.

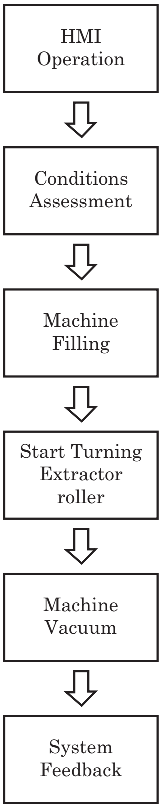
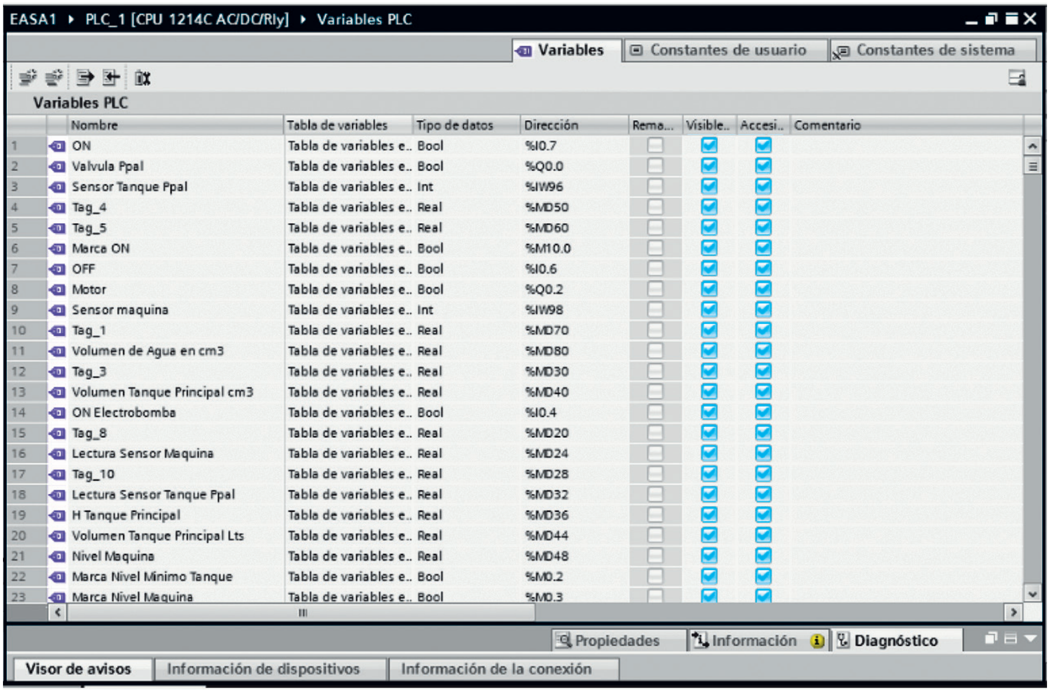


Fig. 19. Software Phase flow
Source: Authors



Variables PLC

	Nombre	Tabla de variables	Tipo de datos	Dirección	Rema...	Visible..	Accesi..	Comentario
1	ON	Tabla de variables e..	Bool	%I0.7	☐	☑	☑	
2	Valvula Ppal	Tabla de variables e..	Bool	%Q0.0	☐	☑	☑	
3	Sensor Tanque Ppal	Tabla de variables e..	Int	%IW96	☐	☑	☑	
4	Tag_4	Tabla de variables e..	Real	%MD50	☐	☑	☑	
5	Tag_5	Tabla de variables e..	Real	%MD60	☐	☑	☑	
6	Marca ON	Tabla de variables e..	Bool	%M10.0	☐	☑	☑	
7	OFF	Tabla de variables e..	Bool	%I0.6	☐	☑	☑	
8	Motor	Tabla de variables e..	Bool	%Q0.2	☐	☑	☑	
9	Sensor maquina	Tabla de variables e..	Int	%IW98	☐	☑	☑	
10	Tag_1	Tabla de variables e..	Real	%MD70	☐	☑	☑	
11	Volumen de Agua en cm3	Tabla de variables e..	Real	%MD80	☐	☑	☑	
12	Tag_3	Tabla de variables e..	Real	%MD30	☐	☑	☑	
13	Volumen Tanque Principal cm3	Tabla de variables e..	Real	%MD40	☐	☑	☑	
14	ON Electrobomba	Tabla de variables e..	Bool	%I0.4	☐	☑	☑	
15	Tag_8	Tabla de variables e..	Real	%MD20	☐	☑	☑	
16	Lectura Sensor Maquina	Tabla de variables e..	Real	%MD24	☐	☑	☑	
17	Tag_10	Tabla de variables e..	Real	%MD28	☐	☑	☑	
18	Lectura Sensor Tanque Ppal	Tabla de variables e..	Real	%MD32	☐	☑	☑	
19	H Tanque Principal	Tabla de variables e..	Real	%MD36	☐	☑	☑	
20	Volumen Tanque Principal Lts	Tabla de variables e..	Real	%MD44	☐	☑	☑	
21	Nivel Maquina	Tabla de variables e..	Real	%MD48	☐	☑	☑	
22	Marca Nivel Minimo Tanque	Tabla de variables e..	Bool	%M0.2	☐	☑	☑	
23	Marca Nivel Maquina	Tabla de variables e..	Bool	%M0.3	☐	☑	☑	

Fig. 18. Inputs and outputs of the system.
Source: Authors

The computer communicates with the PLC via an Ethernet cable, for this, he computer has a network card, which allows such communication .Fig. 20 shows the image of the HMI from the computer.

Once the equipment is in operation, the HMI performs a significant job, as it achieves the display of the system signals. As expected, the HMI performs real-time simulation of the process, indicates the levels of the storage containers, activation of the solenoid valves by LEDs, display of selected variables and buttons ON/OFF of the total system.

The software consists of a parallel section, responsible for the manual control of each of the elements in the system, if necessary, to evaluate their performance individually.

The manual control system can be performed through the HMI or the control board, and the only action that is required is to change the position of a switch that controls the automatic or manual operation of the system.

V. Conclusions

The implementation of this system could bring great benefits of environmental impact, because it was possible to establish frorn the initial gathering of information that there are several companies that produce oily wastewater, but very few actually carry out the appropriate treatment, wasting huge amounts of water and causing a deterioration of the ecosystem caused by pollution from waste oils.

The water obtained at the end of the separation process is not a liquid that is safe to drink, since it is not potable, however, the project results highlighted that this liquid can be reused for other applications, as could be for cleaning floors or sanitary water, achieving savings of this precious liquid.

SCADA systems greatly facilitate monitoring processes; especially, as a relevant aspect in this research project, the possibility of action remotely set, it is enough just by providing the programmable logic controller (PLC) to an Ethernet network to access the system from anywhere in the world, without forgetting, that using this system, the process is vulnerable to cyber-attacks, therefore, it is best kept in a private network system.

The importance of this project is highlighted because little research has been conducted around this subject, which is causing great damage at the environmental level, since oily water is discharged into water sources without any treatment, for this reason the results shown in this article, are a great contribution to help mitigate these adverse effects.

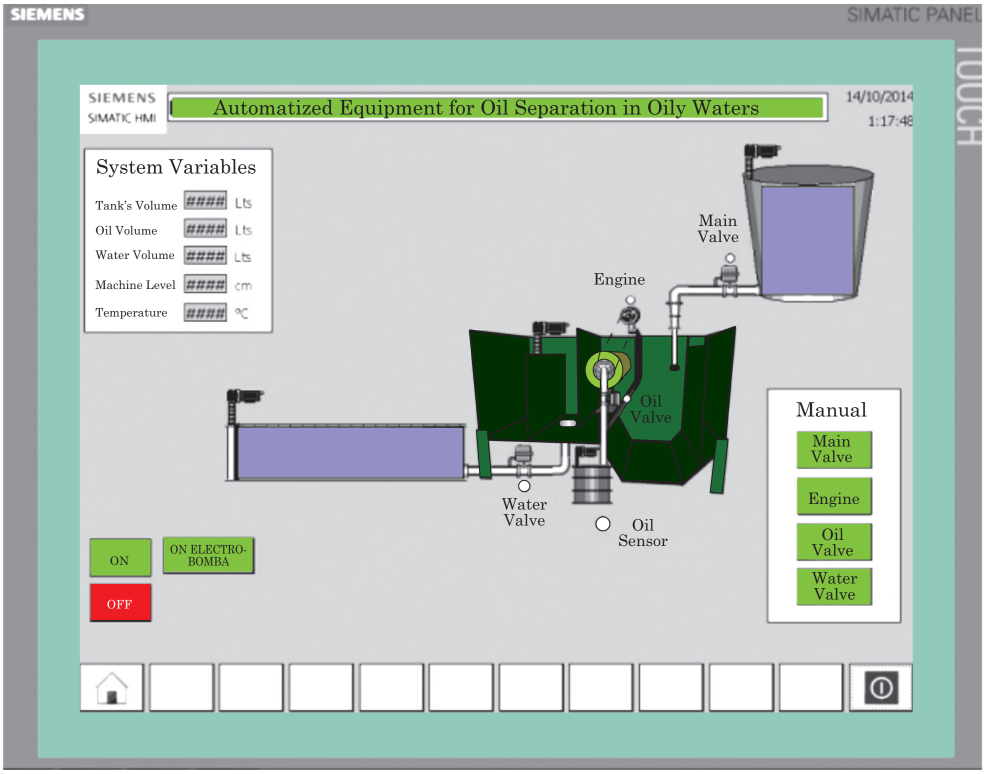


Fig. 20. HM.
Source: Authors

An important aspect that determines a good data acquisition lies in the selection of instrumentation, because it is the instrumentation that sends signals of the measured magnitude to be processed. While it is true that well known market instruments were used, the monitoring of the measured quantities was done with high efficiency.

The research project presented here is a first major step in a hard work that just starts, because from these results an improvement of the system will continue including other variables, as well as the possibility to improve the separation process by subjecting oily fluid to temperature changes.

Analyzing the test results, it appears that the process is efficient and that more than over 90% of wastewater can be recovered, allowing reuse and subsequent saving. This adds to the possibility of knowing the pH data at the end of the process, as the next step of this project will address the possibility of controlling this variable to increase the usability of recovered water.

The mixtures separator equipment not only contributes to environmental conservation but also the academic field since it is a practical tool in the laboratory of the Department of Basic Sciences and Engineering (IBF) of the Universidad de los Llanos.

To present and to display information to the user via PC aids to decision-making processes, not only manually, but also as an automated process. It also helps as a teaching tool for deepening line automation.

The statistical correlation analysis shows interesting results, especially with regard to the error rates in the extraction of oil, which declined to the extent that the amount of applied oil in the mixture was higher.

With the display of variables in the HMI, a big step is taken for future projects, which will seek to improve the system performance, as mentioned above with respect to temperature and pH, using a control action that was presented in the document in a general way.

VI. ACKNOWLEDGEMENTS

The authors of the research project thank their families who gave their unconditional support; Universidad de los Llanos, and Colciencias, who provided financial support for the purchase of material resources; and a special thanks to the Electronic Engineer Germán Londoño and students of Electronic Engineering, University de los Llanos, Jorge Luis Hernandez and William Moreno, for their support and collaboration in the project.

REFERENCES

[1] R. Piedrafita Moreno, *Ingeniería de la Automatización Industrial*, 2nd ed. México: Alfaomega, 2010, pp. 59–80.

[2] J. P. Cruz and M. P. Sánchez, *Automatización De Maniobras Industriales Mediante Autómatas Programables*, 1st ed. Valencia: Universidad Politécnica De Valencia. Servicio De Publicación, 2006, pp. 43–163.

[3] E. Mandado, J. Acevedo, C. Fernández, and J. Armesto, *Autómatas Programables y Sistema de Automatización*, 2nd ed. Barcelona: Marcombo, S.A, 2009, pp. 30–60.

[4] A. Creus Solé, *Instrumentación Industrial*, 8th ed. Barcelona: Marcombo, S.A, 2005, pp. 105–230.

[5] C. Escamilla Resendiz, "Modelación Física de un separador agua-aceite," Instituto Politécnico Nacional, 2010.

[6] J. Behin and M. Aghajari, "Influence of water level on oil–water separation by residence time distribution curves investigations," *Sep. Purif. Technol.*, vol. 64, no. 1, pp. 48–55, 2008. DOI:10.1016/j.seppur.2008.08.009

[7] A. R. Penin, *Sistemas Scada*, 2nd ed. México: Marcombo, S.A, 2007, pp. 30–50.

[8] K. Ogata, *Ingeniería de Control Moderna*, 5th ed. Madrid: Pearson, 2010, pp. 567–595.

[9] R.Hernández, *Introducción a los sistemas de control: Conceptos, aplicaciones y simulación con MATLAB*, 1st ed. México: Pearson, 2010, pp. 361–382.

[10] B. Kuo. *Sistemas de Control Automático*. Naucalpan de Juárez. México. Prentice Hall. 2010. pp 665-714

[11] J. Acedo Sánchez. *Instrumentación y Control Básico de Procesos*. España. Ediciones Diaz de Santos. 2006. pp353-370.

[12] J.A. Romero Rojas. *Tratamiento de aguas residuales. Teoría y Principios de diseño*. Colombia. Editorial Escuela Colombiana de Ingeniería. 2010. pp 17-66.

[13] F. Osorio Robles. *Tratamiento de aguas para la eliminación de microorganismos y agentes contaminantes*. España. Ediciones Diaz de Santos. 2010. pp 10-20)

[14] C, A. Bernal. *Metodología de la Investigación*. Colombia. Pearson Educación, 2010. Tercera Edición. pp 234-258.