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AUTOMATION OF A HORIZONTAL THREE-PHASE CRUDE OIL SEPARATOR

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ABSTRACT

In this document, a horizontal three-phase crude oil separator's automation for the polyphase fluid treatment and the control system integration to the SCADA network (Supervisory Control and Data Acquisition) system are implemented. Knowing the separator's operating principle and the optimum efficiency point that allows a continuous three phases flow (gas, water, and crude) without contamination between them are studied to develop this task. Likewise, the operation and the instrument configuration are investigated for the adequate control of the main variables of pressure, level, and flow within the normal operating fluid parameters such as density, viscosity, and temperature. The control system is developed using PLC (Programmable Logic Controller) to govern the pressure valves and level control loops and achieve the data visualization locally and remotely. The result is a fully automated process that has allowed the treatment of a larger fluid flow from the reservoir polyphase. Consequently, it increases the productivity and efficiency of the oil production plant. The control system works correctly, and the data is sent graphically through an interactive interface. This interface allows the operator to manipulate the process and set alarm levels for pressure variables, level, and setpoints for control valves.

Keywords: automation, crude oil separator, Programmable Logic Controller, SCADA, crude separator.

1. INTRODUCTION

Nowadays, automation processes are becoming more important on an industrial level due to their significant advantages, such as time reduction in the development of tasks or carrying out functions in environmental conditions where an operator cannot access them (Robayo *et al*., 2020). Electronic engineering, in its specialty of control and automation of industrial processes, plays an important role. This area has allowed uninterrupted operations in extreme conditions impossible for a human being, achieving a high quality, profitable, and reliable final product (Creus Solé, 2011).

Advanced process control techniques and devices have become significant in today's industries; this is how a SCADA system notably reduces production losses and the workforce's risks (Otero, 2008). A representative example of applying these techniques is the oil industry, where, requires several processes from its extraction to obtaining different crude oil derivative due to its complex natures. According to engineering studies, knowing the permissible limits to protect the process and avoid contamination and damage to the environment is vital. It is also necessary to study and become familiar with all the elements involved to obtain an optimum operating point (Creus Solé, 2011).

Demand for constantly increasing fuels implies a more significant production for oil exploitation fields, demanding a more extensive, safe, and constant treatment system (Otero, 2008). An automated system allows for an uninterrupted process flow, increased product supply, and less exposure of the production floor to extreme conditions, making it easier to monitor these processes from remote locations (Corrales, 2007). The process efficiency will depend directly on the elements chosen, their configuration, performance, and adjustment. The result is of high quality and avoids affecting the production plant sub-processes.

In the oil and natural gas industry, a separator is a container or vessel for industrial use to produce, process, and treat hydrocarbons to break up the mixture into its basic components, gas and oil. Additionally, it allows isolating the hydrocarbons from other undesirable elements such as water and sand.

Several works related to three-phase separation have been carried out, as is the case of the design of a horizontal three-phase production separator (Benitez and Olmedo, 2011). Another important work is the separation process analysis in a three-phase oil test separator to determine the separation efficiency obtained under the same operating conditions when instrumentation of different technology is used (Miño *et al.*, 2019).

In this document, the automation for horizontal three-phase oil separator polyphase fluid treatment and the control system integration to the network and SCADA system are carried out. The instrumentation used to measure the variables of level, pressure, and flow are designed. Likewise, the control devices that govern the control pressure valves and level control loops and the data visualization are implemented locally and remotely.

2. MATERIALS AND METHODS

The physical separation of liquids and gases is one of the productions, processing, and treatment operations in the oil industry necessary to prevent damage to rotating equipment, avoid corrosion in pipes and meet the quality specifications of natural gas for domestic use (Prieto Jimenez *et al.*, 2019).

2.1 Gravitational Separators

There are three fundamental physical principles for phase separation in gravitational equipment: momentum, gravity sedimentation, and coalescence. Gravitational separators can use one or more of these principles. According to their function as biphasic and triphasic separators, gravitational separators are classified based on their geometry as horizontal or vertical.

2.1.1 Horizontal three-phase separator

The separator's operating principle is quite simple since it mainly takes advantage of the effect of gravity and the difference in phase densities that make up the inlet fluid, as seen in Figure-1 (Viñán, 2013). Using internal mechanical components and physical variables such as pressure and temperature, the separation of gas, water, and oil phases is practically immediate, and the residence time is almost zero. For this to be accomplished, many instruments must carry out the task and attach elements to make up the entire control system. Each instrument is carefully studied to know its physical principle of operation, how it interacts with the process, and what variable it will control to find the most appropriate configuration. This control is as precise as possible and avoids affecting the rest of the production plant.

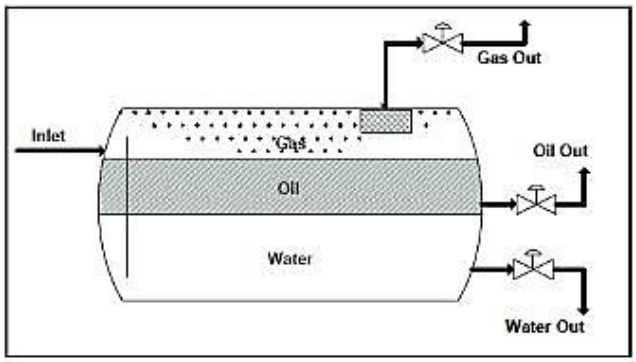

Figure-1. The general operation of the horizontal three-phase separator.

2.2 Transmitters and Indicators

There are several types of transmission signals: pneumatic, electronic, digital, hydraulic, and telemetric. The first three are the most widely used in the industry. In this work, only electrical signals supplied by Smart type electronic transmitters are used for all controlled variables (pressure, level, and flow). The transmitters work under the HART 4-20 mA protocol. Their configuration (range, span, diagnostic, zero, etc.) depends on the variable to be measured; however, all signals are concentrated in the controller's analog input modules (PLC) for processing and control.

2.2.1 Magnetic level indicator

The Magnetic Level Gauge or LG is based on the magnetic tracking, which slides through a sealed guide tube attached externally to the tank and contains a powerful electromagnet. On the outside, there is a hermetically sealed non-porous glass tube equipped with a fluorescent indicator or small magnetic rotating flags that follow the magnetic field of the float. As the level rises or falls, the rotating flags rotate and, as they have different colors on their front and back, they directly visualize the tank level.

2.2.2 Level switches

Level switches are instruments that provide a change in the electrical On-Off signal when the liquid reaches the location where the switch is installed. It is made up of an electrical switch that usually has open and closed contacts that change state when the level is reached (Otero, 2008). In this work, switches are magnetically used and therefore do not require direct contact with the process, thus avoiding leaks or contamination by not using valves, seals, or diaphragms.

2.2.3 Level transmitter

Transmitters are instruments that capture the process variable and transmit it remotely to a receiving device, indicator, recorder, controller, or a combination of these (Creus Solé, 2011). In this work, a contact diaphragm transmitter is used based on the hydrostatic pressure principle to obtain the level measurement.

2.2.4 Pressure measurement

The pressure is physically defined as the force per unit area that a liquid or gas exerts perpendicular to that surface. The pressure can be expressed in different units, which are used depending on the variable magnitude, such as, for example, PSI (Pounds-force per Square Inch) for high values and inches of water ("H2O") for low-pressure values. In this work, the PSI is taken as the pressure unit.
Electronic pressure transmitters with an output signal between 4 to 20 mA work under the principle of having an electrical transducer (which can be resistive, piezoresistive, capacitive, piezoelectric, etc.). This transmitter interacts directly with pressure and sends changes in the electrical signal proportional (and not linear) to the measured fluid or gas pressure.

2.2.5 Gas flow measurement

The flow is the variable that defines the volume of fluid concerning time. The units used vary according to the fluid measured (liquids or gases), and the volume expressed. There are several methods to calculate the flow depending on whether it is a volumetric flow rate or a mass flow rate. Several transducers are developed to measure these flows that allow direct contact with the flow to provide a useful signal representative. The measurement of flow by the principle of differential pressure is the method applied in this work. Differential pressure is generated using an orifice stage to calculate the volumetric flow rate of gas produced by the separator using a flow computer.

2.3 Valves and Actuators

Due to their great variety, designs, applications, and type of operation, the valves are highly used in any industry as cut-off elements (on-off), as final control elements (flow, level, pressure controllers, etc.), or safety systems (relief, pressure and vacuum valves, etc.).

2.3.1 Safety valves

The PSV (Pressure Safety Valve) is mechanical equipment whose function is to release the excess pressure in the equipment connected to the atmosphere whenever the pressure in the container exceeds the safety valve calibration pressure. In this way, further damage is avoided. The safety valve calibration is estimated to be 10% to 15% above the nominal working pressure value for the equipment that protects. There is equipment such as separators, boilers, distillation towers, and closed tanks, which work at a specified nominal pressure. The safety valve behaves as passive equipment if the equipment's pressure does not exceed the value of safety valve calibration. However, as soon as the protective equipment's pressure reaches the calibration value, the safety valve will open, releasing the gases contained within the container into the atmosphere. The safety valve will return to its closed condition when the equipment's pressure value protects returns to the nominal working pressure value.

2.3.2 Control valves

In the automatic control of industrial processes, the control valve is crucial in the regulation loop. It performs the function of varying the control fluid flow rate that it modifies, and it behaves like a continuously variable area orifice. Within the control loop, the valve is generally the final control element. It has as much importance as the primary element, the transmitter, and the controller. It is mainly composed of two parts, the servo motor or actuator, and the body.

2.3.3 Shutdown valves

The SDV (ShutDown Valve) is an instrument located at the input or output of a system to perform a safe fluid shutoff in the event of any failure or emergency. It is part of the emergency system or ESDS (Emergency Shutdown System). The valve is installed at the separator inlet in this work, allowing the polyphase fluid passage for processing.

2.4 Control System

2.4.1 Controller

For this work, a controller from the ControlLogix5000 family reference 1756-L55 is used. These controllers are chassis-based systems, designed to work in harsh environments and have a sequential process system with a communication set capable of handling different protocols or field buses (Ethernet / IP, ControlNet, DeviceNet, DH +, DH485, MODBUS, RS232, HART, and Foundation Fieldbus). The CPU has a memory of 750KB for data/logic and 208KB for I / O modules, status LEDs and fault detection, three-position key selector (Run, Remote, Program), serial port, and backup battery.

2.4.2 HMI

The HMI (Human Machine Interface) is the element that allows the operator to have a process visualization locally to monitor the equipment variables in real-time. This interface executes an interactive application. By pressing keys, the operator can exchange process images, manipulate control PID setpoint values, view alarms, and operate valves in manual mode.

2.4.3 Software

Specific software is used for its design and implementation, and all belong to the Rockwell Automation suite (Rockwell Automation, 2019). Controller logic design, local visual interface (HMI), remote graphical interface, network design, and communication drivers must have a fully functional SCADA system.

3. RESULTS AND DISCUSSIONS

The most appropriate instruments have been chosen to carry electrical signals to the controller. The specific task is executed according to programmed logic, operation area, variable to be controlled, and its importance within the process.

3.1 Level Measurement

In the case of the variable level, four systems are used in the different separator sections. In the separation section where the multi-phase liquid from the production manifold enters, a local indicator of the magnetic type is used, with level switches coupled to control the shutdown valve and the alarm levels in the "high-high" separator., "High", "low" and "low-low". The process variable to control the water outlet control valve is taken by measuring the water-oil level interface from an AGAR probe. This probe's operation is based on a principle of absorption of microwave energy generated by an internal antenna in contact with the fluid that emits a signal absorbed in greater or lesser amounts depending on whether the contact liquid is water or crude oil. And in the oil pocket section, a differential pressure transmitter controls the oil outlet valve, and additionally, a magnetic indicator has been installed for local indication. In Figure-2, the level indicator installed in the oil pocket section is shown.

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Figure-2. Level indicator, crude pocket section.

3.2 Pressure Measurement

For the pressure variable measurement, a Rosemount 2088 (Emerson Electric, 2014) pressure transmitter with HART 4-20 mA protocol configured to measure relative pressure in PSI with a spam of 0 PSI - 100 PSI and alarm levels in 10 PSI (Low-Low), 29 PSI (Low), 65 PSI (High) and 80 PSI (High High) as shown in Figure-3.

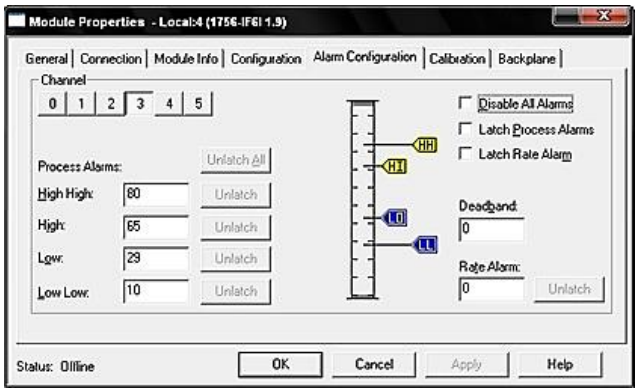

Figure-3. Configuration of alarm levels in PLC for separator pressure.

3.3 Flow Measurement

The principle of differential pressure is to install a body (in this case, an orifice plate) in the pipe through which the flow passes. This plate causes a pressure drop of the fluid, which is proportional to the flow; that is, if there is no flow, the pressure that exists before and after the body is the same and therefore $\Delta P = P1 - P2 = 0$; however, as the flow rate through the pipeline increases, the pressure differential increases. The stage consists of a perforated plate with a variable size orifice installed in the pipe in a flanged manner or through orifice boxes or plate holders. For differential pressure measurement, two connections are used before the plate and after the plate, which allows taking the pressures before (PB) and after (PA).

Figure-4 shows the set of elements used for gas flow measurement, where it can see the stage holder and internal stage (1), the pressure taps before and after the stage (2) that are connected to the sensor. Also, it can see the differential pressure (3) and flow computer (4).

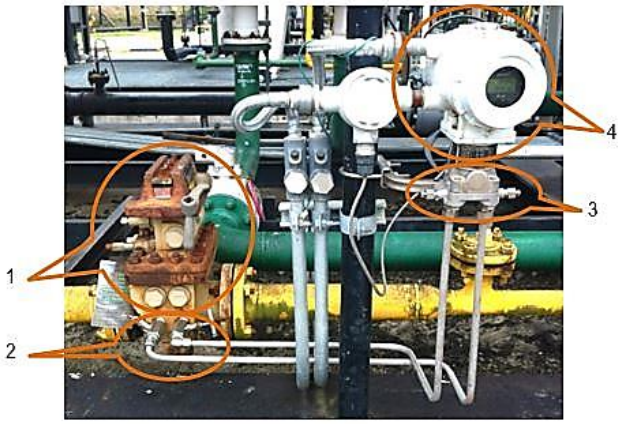

Figure-4. Elements for gas flow measurement.

As an additional measure, a flow computer installed at the gas line outlet is used to know the separator's flow. This equipment's function is to measure the gas flow through an orifice plate under API 1992 (American Petroleum Institute) and AGA (American Gas Association).

3.4 Valves and Actuators Installed

In this work, two safety valves are installed adjusted to a set pressure of 95 and 100 PSI to protect the separator in case of overpressure. They are in the upper part of the vessel in the separation zone, as shown in Figure-5. The fluid handled is gas, so it cannot be discharged into the atmosphere. The firing of the PSV is conducted through a pipe to a high-pressure scrubber that takes the gas directed to the Tea (gas flare) for combustion.

Figure-5. Safety valves installed.

For this work, the actuators command direct-acting rotary motion shutters (air to open) normally closed with 2", 3", and 4" butterfly valves for the gas, oil, and water lines, respectively, which have FieldVue digital positioners, as shown in Figure-6. These actuators are communication instruments based on a microprocessor and a pneumatic current converter. In addition to its primary function of converting an input current signal to a pneumatic pressure as an output signal, it uses HART protocol communication giving easy access to critical information for the process operation. Functions such as valve tag, messages, process variable review, date, and diagnostic parameters can be accessed via a field communicator.

Figure-6. Control valves in water lines.

The separator's fluid inlet is controlled by a direct-acting shutdown valve with closed and open positions only, as seen in Figure-7. The valve has travel switches for closed and open indications taken to the control system to view the valve status. It has a pneumatic actuator attached to a globe-type valve that, under normal conditions, allows the passage of fluid into the separator and closes under the alarm conditions established in the control logic. Once completed, the operator must on-site verify the fault condition and manually restore equipment operation.

Figure-7. Shutdown valve installed.

3.5 Control System (Hardware)

The control system used in the project is entirely from Rockwell Automation's Allen Bradley brand. The control hardware is made up of chassis, modules, CPU, and HMI. All the elements are located in an exploitation proof type cabinet following the classified areas' regulations, as shown in Figure-8. The control system is modular; a 10-slot chassis is required for the controller CPU location, communication modules, and I / O modules. All modules are electrically powered by a 24VDC source located on the left side, and a backplane carries out communication between them.

The controller belongs to the ControlLogix 5000 family with a comprehensive set of instructions for the logic design and can handle different communication protocols such as RS-232, RS-485, Ethernet, MODBUS, and others. Different types of I / O modules are used to connect different instruments and control signals, and their characteristics depend on the kind of instrument. For example, the signal from level switches is connected to a digital input module. Pressure and level transmitters are connected to an analog input module, and control valves are connected to an analog output module, etc.

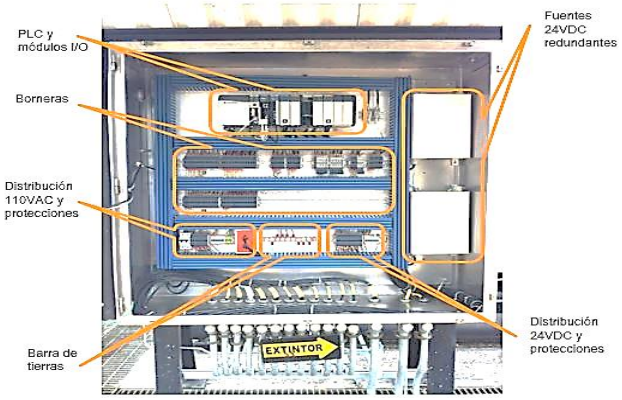

Figure-8. Control cabinet.

HMI is the element that allows the operator to visualize and interact with the process through an application that is run by design software. It can view separator operation variables by navigating different screens, adjust setpoint values, operate the shutdown valve, view process alarms, etc. The HMI is installed in the control cabinet door and communicates with the controller through a serial cable using an RS-232 port.

3.6 Control System (Software)

For the visual interface development of this work and the control logic design, different programs are used, each one focused on a specific function. In the case of control logic, it is designed in the RSLogix5000 program, where all the steps that the controller must execute for the separator operation are written in Ladder language. It is also used for chassis configuration, controller selection, alarm configuration for analog input modules, tag creation, etc.

Two different programs are used for the interactive application design (local and remote), with many standard features. FactoryTalk View Machine Edition uses the RS-232 port for serial communication with the controller through a point-to-point cable with DB-9 connectors for the local system. The application consists of several screens where the operator can view the equipment variables, make specific changes, and adjust setpoint values shown in Figures 9 and 10.

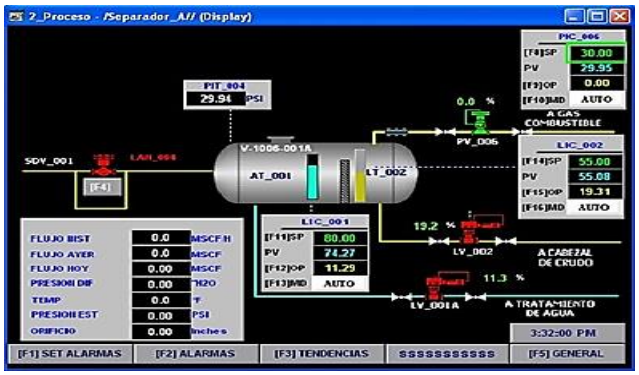

Figure-9. A general screen of the separator in HMI.

Figure-10. PID parameter setting screen in HMI.

For the remote monitoring application, the FactoryTalk View Site Edition for Distributed Applications program is used and is integrated into the existing system. A mimic of the separator is attached to the main supervision screen of the production facilities area, which, when clicking on it, opens a new window where all the separator variables in the control cabinet are illustrated as shown in Figures 11 and 12.

Figure-11. The main screen of production facilities area in supervisory.

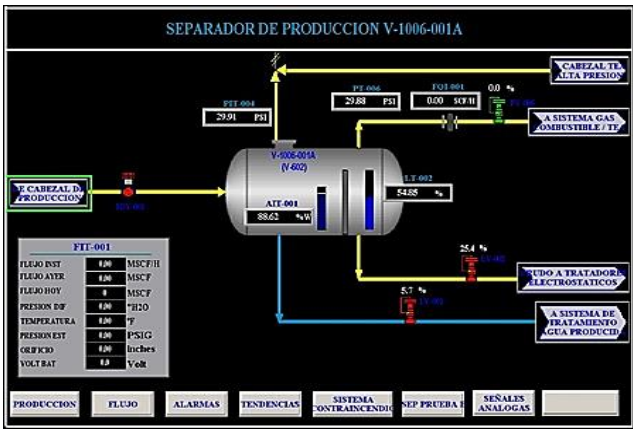

Figure-12. A screen of variables separator in supervisory.

3.7 Comments on the Results

The control system maintains a constant operation of the separator through the sequential execution of the programmed logic. Each logic step regularly

examines the variables taken from all the instruments and takes an informative action in a process alarm or corrective in a shutdown signal. In this case, the inlet valve is closed, preventing the liquid from flowing into the separator. The gas, water, and oil control valves return to their normally closed position, containing the separator from losing operating conditions. In the event of an alarm signal, the operator must go to the site and verify the signal's requirement to take the necessary actions within his reach to reestablish the separator. If the condition is not reestablished, the operator must verify the instrument that presents said condition.

In the event of a shutdown signal, the operator must verify that the process condition that generates the alarm is correct to adjust the setpoints, to allow a greater or lesser amount of the variable that produces the signal. This condition can generally be made by an abnormal process condition such as the excessive increase inflow to the separator produced by the wells' patching or a measuring instrument's failure.

When the process conditions are expected, the separator continuously controls the three phases of control valves to maintain a continuous balance and flow of water, gas, and oil. Samples are taken several times a day at the water and oil lines' output to verify the phase's quality and make the necessary adjustments since all the wells' production is not constant in terms of the water-oil ratio.

4. CONCLUSIONS

The importance of process automation in the crude oil treatment chain was demonstrated through this work's development. Excellent results were obtained in the polyphase fluid separation in its three phases without affecting the process, equipment, or human life.

Knowing the instrumentation performance's physical principle is essential to carry out a correct system configuration; select a range, communication protocol, sensor, or transmitter type. A wrong choice leads to economic losses for the company with a system that works irregularly or outside the established parameters.

It is essential to generate a work plan when designing a SCADA system that allows detailing all the elements that make up the system and how they interact. Implementing a strategy that will enable each of the processes to work sequentially, attend to the needs of the process, and seek the desired results, helps provide high reliability and security for users who interact directly with the application.

The software knowledge and management offered by Rockwell Automation in the line of process control and SCADA systems provide essential support in the automation process.

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