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PLC–Based Control of the Bitumen Extraction Technological Process

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Abstract

This article investigates the technological process of bitumen production and the application of a PLC-based automatic control system to improve process efficiency and product quality. The study aims to develop an automated control approach capable of ensuring stable operating conditions and standard quality indicators during bitumen production. The bitumen production process, based on the oxidation of a mixture of vacuum residue or vacuum residue with Avtol-15 in the presence of air, as well as the influence of process parameters and automation tools on production performance, are scientifically analyzed. Considering the depletion of natural oil reserves, the growing demand for petroleum bitumen, and the difficulty of obtaining high-quality products from processed feedstock, the implementation of advanced automation technologies has become increasingly important. As a result, a PLC-based control system with an HMI interface was developed for automatic operation of the unit. The proposed system provides more reliable process control, increases production profitability, and ensures compliance with standard quality requirements.

Keywords: bitumen production, control system, PLC controller, human-machine interface (HMI), actuator

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Bitum istehsalı texnoloji prosesinin PLC kontrolleri əsasında idarə olunması

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Xülasə

Məqalədə bitum istehsalının texnoloji prosesi və onun səmərəliliyinin artırılması məqsədilə PLC kontrolleri əsasında avtomatik idarəetmə sisteminin tətbiqi tədqiq edilmişdir. Tədqiqatın məqsədi bitum istehsalı prosesində texnoloji parametrlərin sabit idarə olunmasını təmin edən və məhsulun standart keyfiyyət göstəricilərini qoruyan avtomatik idarəetmə sisteminin işlənib hazırlanmasıdır. İşdə vakuum blokundan alınan qalıq-qudronun və ya qalıq-qudron və Avtol-15 qarışığının hava iştirakı ilə oksidləşmə-reduksiya prosesi, texnoloji parametrlərin idarə olunmasının xüsusiyyətləri və avtomatlaşdırma vasitələrinin tətbiqi elmi-praktik baxımdan təhlil edilmişdir. Təbii neft ehtiyatlarının azalması, emal olunmuş xammaldan yüksək keyfiyyətli bitum alınmasının mürəkkəbliyi, həmçinin neft bitumuna artan tələbat istehsalda müasir avtomatlaşdırma texnologiyalarının tətbiqini zəruri edir. Aparılmış tədqiqat nəticəsində qurğunun PLC kontrolleri və insan-maşın interfeysi (HMI) əsasında avtomatik idarəetmə sistemi işlənilmişdir. Təklif olunan sistem istehsal prosesinin etibarlılığını və rentabelliyini artırmağa, həmçinin bitumun standart keyfiyyət göstəricilərinin təmin edilməsinə imkan verir.

Açar sözlər: bitum istehsalı, idarəetmə sistemi, PLC kontroller, insan-maşın interfeysi (HMI), aktuator

Управление технологическим процессом добычи битума на основе PLC контроллера

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Аннотация

В статье исследуется технологический процесс производства битума и применение автоматизированной системы управления на базе PLC для повышения эффективности производства и обеспечения стандартных показателей качества продукции. Целью работы является разработка системы автоматического управления, обеспечивающей стабильное протекание технологического процесса и поддержание требуемых параметров качества битума. В работе выполнен научно-практический анализ процесса окислительно-восстановительной переработки смеси остаточного гудрона вакуумной установки или смеси остаточного гудрона с продуктом Avtol-15 в присутствии воздуха, а также особенностей управления технологическими параметрами и применения современных средств автоматизации. Истощение запасов природной нефти, сложность получения высококачественного битума из переработанного сырья и рост потребления нефтяного битума обусловливают необходимость внедрения современных технологий автоматизации. По результатам исследования разработана система автоматического управления установкой на базе PLC-контроллера и человеко-машинного интерфейса (HMI). Предложенная система обеспечивает более надежное управление технологическим процессом, повышение рентабельности производства и получение битума, соответствующего стандартным требованиям качества.

Ключевые слова: производство битума, система управления, контроллер PLC, человеко-машинный интерфейс (HMI), актуатор

Introduction

Bitumen is a dark brown hydrocarbon-containing product obtained from crude oil and has many uses. Bitumen is mainly used in road construction, in the manufacture of plastics and other products. About 90% of all bitumen used in industry is synthetic bitumen. It has already been mentioned that the technological process of bitumen production involves the oxidation-reduction process of residual resin obtained from a vacuum unit or vacuum column and Auto-15 product with air. The oxidation-reduction reaction is carried out at a temperature of 250˚C÷270˚C at atmospheric pressure. The reaction that occurs during the oxidation-reduction process is exothermic. The reaction time depends on the amount of product produced. In addition, the reaction time is influenced by the process pressure and the amount of air [1-2].

If the amount of air added to the reaction exceeds the set standard value, the reaction time is reduced and the concentration of oxygen O_2 in the separated gas also increases. If other parameters remain unchanged, a prolonged oxidation reaction leads to a change in the hardness of the bitumen produced. A prolonged oxidation process leads to the formation of solid bitumen. The normal temperature for the oxidation process is 250–270 °C, and the normal pressure during the process is 0–2 kg/cm². If the temperature in the gas environment rises above 300 °C, this will cause the environment to ignite. As a result of the temperature in the liquid environment exceeding 300 °C, a coking reaction may occur in the bitumen produced. A decrease in pressure below the normal value leads to an increase in reaction time [3].

On the other hand, the nature of the aggregates can affect the aging of the bitumen. First, it has been determined that some mineral components on the aggregate surface can catalyze the oxidation of the bitumen. Secondly, aggregates can be electrically charged by moisture on their surfaces due to the ionization of their minerals. These factors indicate the complexity of the technological characteristics of bitumen production. For these reasons, existing control and regulation schemes cannot ensure the necessary economic performance at this enterprise.

Therefore, when creating an optimal control system for any technological process, the nature of the changes in both the external and internal material flows that characterize this process must first be determined.

Purpose of the work

Development of a controller-based control system using the FBD programming language at the operational management level, taking into account the specific features of the technological regulations in the operating modes of the technological processes for bitumen production.

Problem statement

The bitumen plant control system includes several key components:

• PLC controller – the central element of the system, responsible for automating technological processes.

• Sensors and actuators – collect data and execute equipment control commands.

• Operator display interface – allows the operator to monitor the system status and make adjustments.

• Communication networks – provide communication between the PLC, sensors, actuators, and the interface.

The operation of a PLC-based bitumen plant includes several stages:

1. Raw material loading: Sensors monitor the level and quality of raw materials, and the PLC controls the feed of materials into the process line.

2. Heating and processing: The PLC regulates the temperature and pressure in the boilers and reactors, ensuring optimal conditions for bitumen production.

3. Filtration and cooling: After processsing, the product passes through filtration and cooling systems, the parameters of which are monitored by sensors and controlled by the PLC.

4. Filling and packaging: The final stage includes automatic filling and packaging of the finished product, which is also controlled by the system.

The PLC continuously monitors all process parameters, automatically adjusts processes, and initiates emergency shutdowns in the event of malfunctions. This approach improves safety, reduces human error, and ensures consistent product quality [4,5].

Overall, using a PLC to control a bitumen plant enables high precision, reliability, and efficiency of the process, which is essential for the company's competitiveness and compliance with In general, PLC is a device that provides remote control of the entire process. For this process, Honeywell's ControlEdge PLCs are used. This PLC is part of the Controledge family and provides unprecedented connectivity at the level of all process operations.

Honeywell's advanced Programmable Logic Controller (PLC) technology increases control by offering greater flexibility and lower costs. Reduces installation efforts by using security updates. Controledge PLC users benefit from easier configuration, efficient operations and less maintenance, as PLCs help free complex personnel from manual management. The use of the OPC UA protocol and embedded cybersecurity seamlessly integrate into various tools, equipments.

Solving of the problem

Production process control and precise adherence to recipes are achieved using a programmable logic controller (PLC).
Detailed information about the operation of the unit is displayed on the operator's workstation screen in the form of mnemonic diagrams. The mnemonic diagram informs the operator about the process parameters in real time and allows remote control of the bitumen production process. Based on the collected data, the APCS controller generates control signals for the actuators [6,7].

The automated production control system (APCS) of the plant can be easily integrated into the enterprise's automated control system to transfer information about the plant's operation using an industrial data exchange protocol. İt is shown in figure 1.

Supported ControlEdge PLC protocols: Modbus TCP protocol, OPC UA protocol, HART-IP protocol, CDA protocol.

I/O module. ControlEdge PLC supports various I/O modules. The following I/O modules are included in this process:
- Universal I/O module, 16 channels
- Universal analog input - RTD, TC, V, 8 channels
- High-level analog input, 16 channels
- Analog output, 4 channels
- 120/240 V AC digital input, 16 channels
- 24 V DC digital input, 32 channels
- Digital input contact, 16 channels
- Digital output 120/240 V AC, 16 channels
- Digital output 24 V DC, 32 channels
- Digital relay output, 8 channels

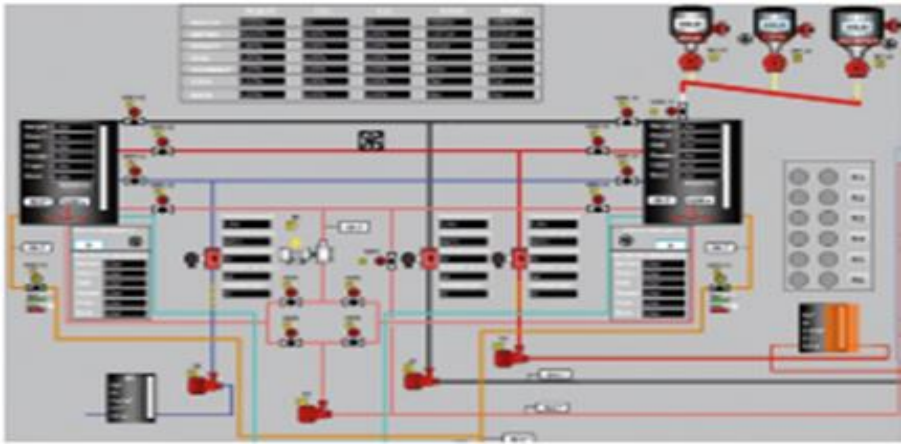

Figure 1 – Automated production control system of bitumen production

Table 1 - Performance and capabilities

Maximum input/output modules for the controller	144
Maximum analog inputs for the controller	2304
Maximum number of entries for the controller	4608

As mentioned above, the FBD programming language was used for this process. This language has many advantages over other languages in some cases [8,9]. First, you need to create a project. Then, according to the process, you need to use logic elements (LE), an RS trigger, and a comparator, which is a comparison device. İt is shown in figure 2. As is known, here, based on signals coming from the controllers, the actuators must open and close within certain limits. This is determined by the PLC based on the signal coming from the controller, and the necessary signal is fed to the output. For example, if 0 V is received from the controller, this means that a zero level signal is sent; conversely, if 5 V is received, this corresponds to a first level signal. There is a certain range of limits, i.e., a voltage of 0÷2 V indicates the need for a zero level signal, and 2.5÷5 V indicates the need for a first level signal. It is clear that digital signals are not always required. As is well known, PLCs receive analog signals and transmit them from the output. Since there are many parameters in the oil industry, such as flow rate, temperature, level, and pressure, analog signals are often used. However, the sample program we have prepared only takes digital signals into account.

If we move on to the program's explanation, we see that the input signal from the TIC 101 regulator for input signal I1 is given to the comparator's input. This signal is called the Enable, or permission signal. Then, values corresponding to the process are provided to the NUM blocks. The NUM 120 block is intended to function like a TE 101 sensor. If the signal from here differs from the value entered into the NUM 119 block, a signal will be sent to the output, i.e., to the TCV 101 actuator.

This sequence will be the same for FIC 1101, TIC 1201, and LIC 1205. To regulate the flow of air and water from the compressors and water tank, the signals from regulators FIC 1202 and FIC 1401 are given to an AND element. When both signals are 1, a signal is sent to the necessary actuators at the output. Then, if the post-comparator signal from the

LIC 1205 regulator is active, it will send a 1 signal to the R-reset input of the RS trigger placed before the outputs of all the aforementioned elements.

This will deactivate those outputs. In other words, if the level in the reactor rises too high, there will be no need to adjust the other actuators; the signal will be sent directly to the LCV 1205 actuator. As we know, the signals sent can be analog or digital. These signals are converted by the converters located next to the actuator and then enter the actuator.

The human-machine interface (HMI) screen, created using Siemens SIMATIC WinCC Runtime Advanced software, is shown for process control and monitoring.

The HMI of control system for bitumen production is shown in figure 3.

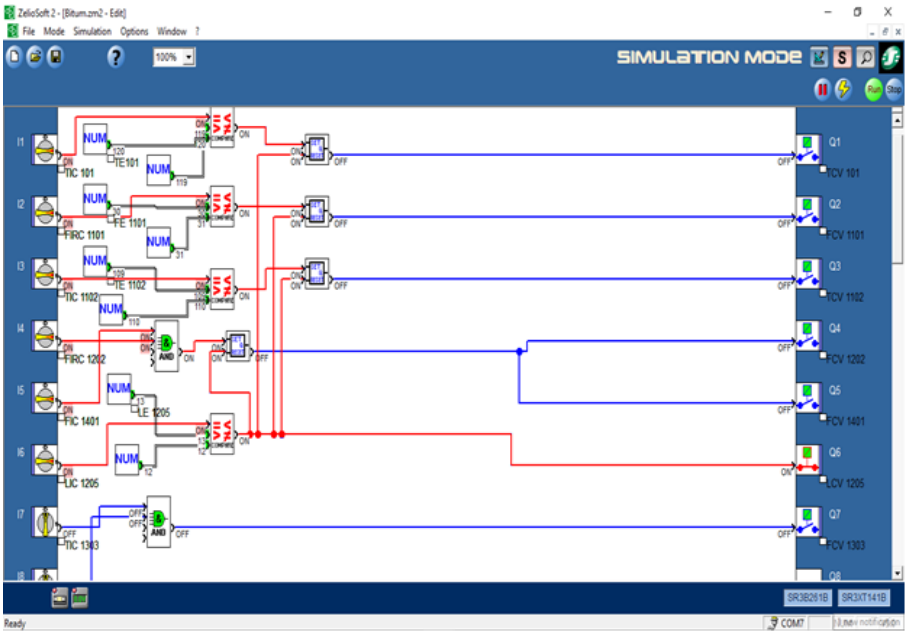

Figure 2 – Software for PLC

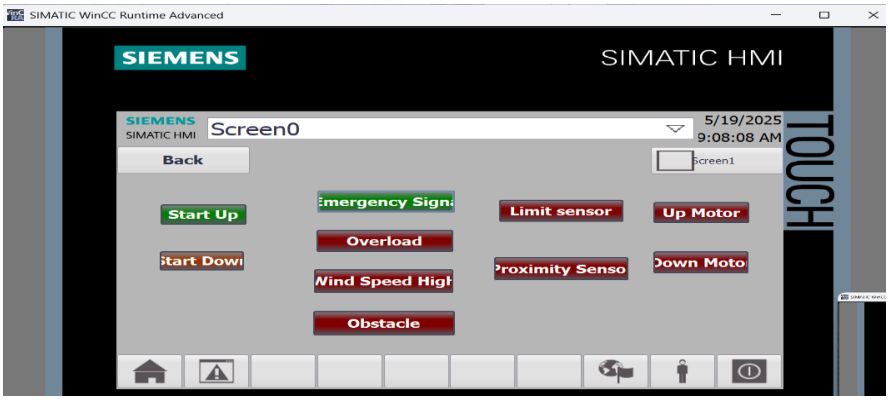

Figure 3 – HMI of control system for bitumen production

It contains the following control elements:
various buttons are provided to simulate the status of sensors and motors, for example:

- Start Up
- Limit sensor
- Up Motor
- Overload
- Down Motor
- Obstacle

The buttons allow you to switch between screens ("Back," 'Screen1') and possibly other functions such as "Start Up" and "Emergency Signal." Operators use the HMI to start and stop equipment (as shown in the image by the "Start Up" and "Down Motor" buttons), change operating parameters, and troubleshoot malfunctions. The system monitors critical events (e.g., "Emergency Signal," "Overload," "Obstacle") and notifies operators about them and can also generate reports.

Conclusion

This research paper examines the operating mode of bitumen production, which has a complex technological structure and nature, and identifies the main factors affecting the operating mode of the process. A control system was developed based on the parameters affecting the normal operating mode of the process.

A PLC Controledge controller with a simpler configuration was used, capable of easily integrating network protocols such as Modbus TCP Protocol, OPC UA Protocol, HART-IP Protocol, and CDA Protocol. The FBD (Functional Block Diagram) programming language was used for this controller.

Conflict of Interest

The author declares there is no conflict of interests related to the publication of this article.

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