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MODERNIZATION OF THE WATER PURIFICATION SYSTEM FOR SEWAGE TREATMENT PLANTS USING SCHNEIDER ELECTRIC EQUIPMENT

Abstract

Currently, the issue of modernization of outdated automatic control systems at strategically important infrastructure facilities of the city, such as water supply and water treatment, is urgent. Using modern automation equipment allows for improving the environmental situation and increasing the reliability of technological processes. This article discusses the development of a new automated system for the biological treatment facility of the Almaty Su sewage treatment plant to replace the outdated current automation. A control system for air conditioning machines, based on Schneider Electric equipment, has been developed using EcoStructure Control Expert software to manage the Modicon M340 controller. Additionally, using EcoStructure Machine Expert, a control system has been created for air injection machines during the biological cleaning phase, which uses the Modicon M241 controller.A process control mnemonic circuit was designed to switch between Modicon M340 and M241 controllers. Remote I/O architectures were developed using the Architecture Builder to create network configurations. An emergency protection system was implemented on Honeywell equipment at Kazakh-British Technical University (KBTU) JSC, using Safety Controller and Manager tools. Security levels at SIL enterprises were calculated.

Key words: water supply, automation system modernization, supercharger, blower, programmable logic controller.

Introduction

Sewerage systems in large cities have an impact on public health and the comfort of life of the population. With an increase in the number of people and a worsening climate, the importance of modernizing and automating these systems is increasing. The overload of sewer systems during heavy rainstorms also has a significant effect. In many cities in Kazakhstan, the outdated sewage system is hindering operations. It is essential to modernize the sewage treatment system in a timely fashion, as it may later become overloaded, leading to equipment failure and an emergency on the part of the facility.

Wastewater treatment is a complex technological process that takes place in several stages. In the first stage, the water undergoes mechanical cleaning. Drains are directed to grates and sand traps. The grilles are filtering, separating large debris from the stream. Wastewater flows through the vertical plates of the grids, while large inclusions remain in the gaps between the plates. The captured debris is removed using scrapers. After the gratings, sand traps follow at the stage of mechanical cleaning. This stage is designed to purify streams from lighter organic substances. Further, the water enters the primary settling tanks through the "averagers". Following the primary sedimentation tanks, the wastewater enters the stage of biological purification. Biological cleaning involves the use of microorganisms, namely activated sludge. The activated sludge consumes the substrate, that is, it removes the smallest impurities, suspended particles, and fine suspension. Biological cleaning takes place in special tankers «aerotanks». After the activated sludge stage, water purification is carried out at the expense of chemicals. Finally, the water is released into designated water reservoirs.

Literature review

The main task is to develop a water supply system automation system that matches the parameters and structure. Sewage treatment plants are an essential part of this system. The general principles of the automation systems for all industries are similar. It is necessary to create a system that embodies the technology for performing the assigned tasks [1]. In the process of wastewater sedimentation, situations may occur that hinder work. The main problem is the neglect of the influence of flow density. To do this, elements can be installed to control and direct the flow, which will increase deposition [2]. The task of designing and modeling settling tanks is necessary for the development of wastewater treatment systems. It is also necessary to take into account innovations to improve the efficiency of the system [3]. To develop and analyze the structures of wastewater treatment plants, it is important to study a technological concept. The wastewater treatment process follows a step-by-step process to achieve high-quality results. It is necessary to use technologies to clean fine particles to effectively treat wastewater [4].

To develop automation systems, it is necessary to investigate a mathematical model for stability, controllability, and observability [5]. The need for a mathematical model of the selected control object lies in the ability to predict and evaluate the behavior of the process [6]. To analyze mathematical models of a control object, one must master the sections of mathematics widely used in engineering practice [7]. To generate a control signal and analyze deviations from the set value, a PID controller must be integrated into the system [8]. There are various methods of setting up PID controllers, not only well-known, but also completely new algorithms for working with regulators [9]. While studying problems related to regulating a system, a research paper on the creation of a regulator based on fuzzy logic principles was considered [10].

In an article from the Schneider Electric blog, there is indisputable evidence of the need to modernize the systems [11]. The program for the controller's firmware was created using Schneider Electric's EcoStructure Control Expert software [12]. Security system has been created for the designed system and SIL has been calculated [13].

Main provision

The control object and the technological process of water purification

The technological process of water purification involves the stages of mechanical, biological, and chemical cleaning. Biological stage of water treatment takes place in aeration stations, where active sludge located in the aerotanks participate in the process. Activated sludge is a collection of bacteria that participate in wastewater treatment and oxygen supply to the aerotank is necessary for its vital activity. Oxygen enters the aerotank through blowers, with the supercharger being the main component in the blower system.

The supercharger was used as a control object. Superchargers are an important part of cleaning stations, and they are used to provide aeration and air circulation during various cleaning processes. They play a role in supplying air to biological reactors, aerobic biological filters, oxidative recuperators, and other wastewater treatment systems. Blowers help create optimal conditions for the activity of microorganisms and chemical processes, ensuring effective cleaning.

Figure 1 shows a block diagram of the biological stage in water purification. The block diagram was created according to the real scheme from the aeration station.

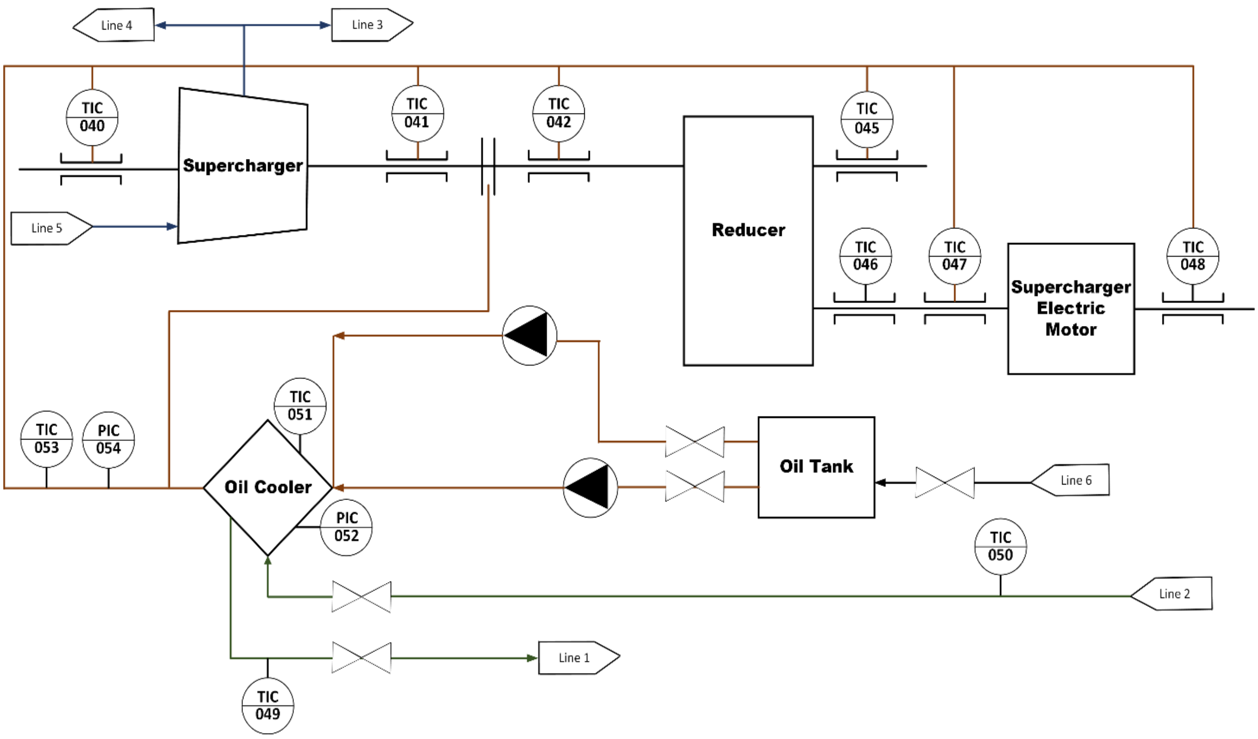

Figure 1 – Structural diagram of the biological cleaning process

Table 1 shows the parameters of the actual operation of the blower. The data was taken from the Almaty Su aeration station.

Due to the aeration process, oxygen reaches microorganisms. The blowers provide oxygen to the aerators, where it needs to be maintained at a certain level during the wastewater treatment process. The air can be supplied by the blower due to the operation of the supercharger and its electrical motor, gear box, oil tank, and oil cooler (Figure 1).

For the development of the automation system, data from Almaty aeration station and Almaty Su Company were used as a basis. The object of control is a supercharger (Figure 2). Superchargers in wastewater treatment plants, also known as blowers, are devices used to supply compressed air to such plants. These machines are found at the stage of biological treatment of wastewater.

Table 1 – Data of the technological process diagram

Parameter:	Indicator:	Value:
The temperature of the support bearing No. 1 of the supercharger.	TIC-040	52,5 °C
The temperature of the support bearing No. 2 of the supercharger.	TIC-041	52,5 °C
The temperature of the support bearing No. 1 of the reductor.	TIC-042	36,5 °C
The temperature of the support bearing No. 2 of the reductor.	TIC-045	36,5 °C
The temperature of the support bearing No. 3 of the reductor.	TIC-046	36,5 °C
The temperature of the support bearing No. 1 of the electro motor.	TIC-047	56,9 °C
The temperature of the support bearing No. 2 of the electro motor.	TIC-048	45,8 °C
Water temperature parameters for cooling.	TIC-050	42,5 °C
The temperature of the cooling water at the outlet.	TIC-049	44,9 °C
Oil temperature parameters at the oil tank inlet.	TIC-051	45,6 °C
Oil pressure parameters at the oil tank inlet.	PIC-052	0.432 MPa
Oil temperature parameters at the outlet of the oil cooler.	TIC-053	45,5 °C
Oil pressure parameters at the outlet of the oil cooler.	PIC-054	0.186 MPa

Figure 2 – Supercharger and the outlet pipe of the blowers
of the aeration station, Almaty city

Figure 2 – The injection machine and the outlet pipe of the blowers in the aeration station in Almaty for wastewater treatment, the blowers can generate high compressed air pressures. Compressed air is piped into the aerotank. Biological purification uses microorganisms, specifically activated sludge, which needs oxygen (Figure 3).

Figure 3 – Aerotanks for biological water purification
of the Almaty Su enterprise using activated sludge

For the aeration station, it is proposed to develop a modern automation system by replacing outdated equipment. Blower systems still operate on outdated equipment, and the automation system has not been changed since Soviet times.

Materials and methods

Mathematical model of the control object

To analyze and study the control object and to select the coefficients of the regulator, it is necessary to calculate the transfer function's value [5]. The dynamic relationship is expressed using a differential equation. For a first-order system, the differential equation is given by the formula:

$$\frac{dQ_{out}}{dt} + Q_{out} = K\omega_{in} \quad (1)$$

In order to accurately describe the operation of the control system, it is necessary to proceed with the consideration of the transfer model. According to the formula above. Where the important role is played by the variable *s* that is the Laplace transform variable. Through calculating the ratio of output power to input power in the Laplace domain to obtain the result of the transfer function for the blower:

$$W_p(s) = \frac{Q_{out}(S)}{\omega_{in}(S)} = \frac{K}{\tau s + 1} \quad (2)$$

Define the input and output variables: in ω_{in} – rotational speed of the blower (input); out Q_{out} – airflow rate from the blower (output). Where K – Gain or amplification factor, τ – air blower time constant. From the technical information about the air blower used at the facility, it is known that $K = 5$ and $\tau = 0.2$:

$$W_p(s) = \frac{5}{0.2s + 1} \quad (3)$$

To improve the characteristics of the transient process, the PI controller will be automatically configured using Simulink automatic settings in the MATLAB environment. Due to the automatic adjustment function, the optimal values for the PI controller's coefficients were obtained as follows. The controller's parameters, performance, and reliability are shown in Table 2. Although the rise time and settling time after setting decreased, the overshoot slightly increased due to the integral part's action from the controller and lack of a derivative component.

Table 2 – The main PI controller parameters and characteristics of system

Characteristics of system	Tuned	Block
1	2	3
P	1.0198	1
I	8.4255	1
D	0	0
Rise time	0.0572 sec	0.0863 sec
Settling time	0.341 sec	0.823 sec
Overshoot	8.45 %	0 %
Peak	1.08	0.996
Phase margin	90 deg, 32.2 rad/s	92.5 deg, 29.5 rad/s
Closed-loop stability	Stable	Stable

For a more visual understanding of the behavior of the control system, should be compared different types of controllers: PID (Proportional-Integral-Derivative) and PI (Proportional Integral) controllers. Figure 4 represents the results of a structure diagram with two controllers and a closed control system without any controllers.

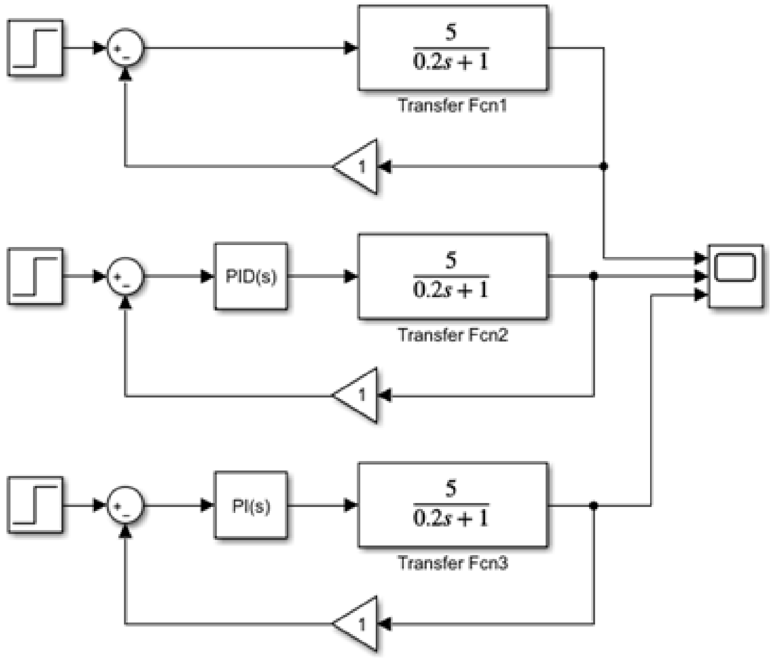

Figure 4 – Structure diagram of closed system with PI and PID controllers

There is graph (Figure 5) of the system with PID, PD. On the graph, there is a sharp change in the trajectory of the graph with a polyline in PID controller. The graph of PID controller of has excessive overshoot and long settling time, which negatively impact stability and performance.

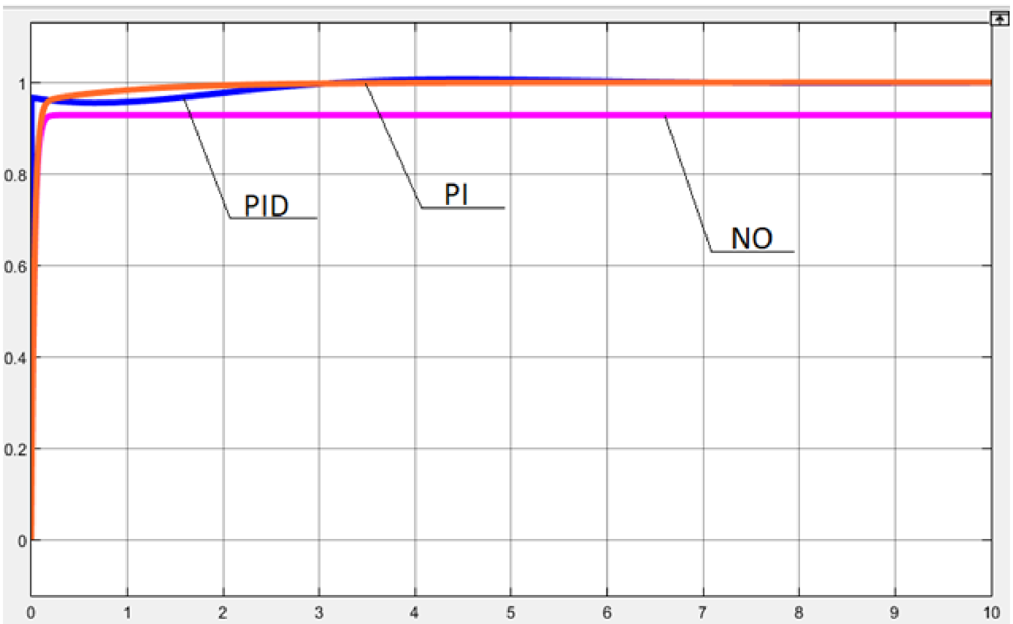

Figure 5 – Graphs of comparing closed system with PI and PID controllers

The graph illustrates how the PI controller addresses initial process fluctuations, stabilizing the system to the desired level. Comparative analysis of closed systems, with and without the PI controller, demonstrates improved transient process quality.

Development of the remote I/O architecture using the Architecture Builder software product

Let's consider the architecture of the wastewater treatment process, including mechanical, biological, and chemical treatments, based on Schneider Electric equipment controlled by a Modicon M340 controller. Figure 6 shows remote I/O devices configured to communicate with the controller using Modbus communication modules.

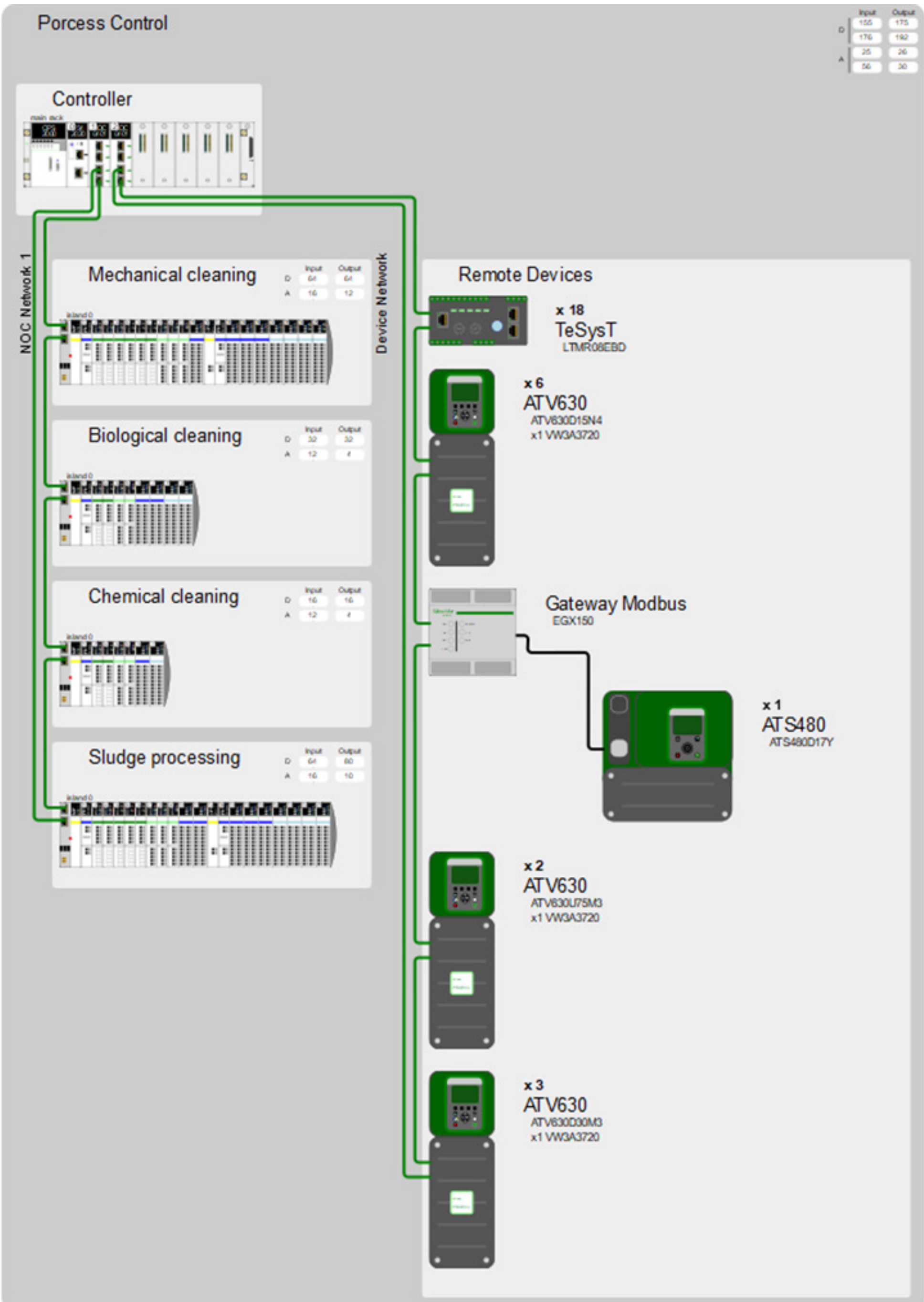

Figure 6 – Implementation of the wastewater treatment system on the M340 controller

Table 3 shows a fragment of the specification of the modules of the main bus of the M340 controller. In addition to the processor module and the power supply, only communication modules are located on the controller bus.

Table 3 – Specification of the M340 controller modules on the main bus

Reference	Description of the module	Location	Quantity
BMEXBP0800	Backplane X80 8 slots ethernet	Process Control/PLC	1
BMXP342020	M340 CPU Level 2 – Modbus / Ethernet	Process Control/PLC	1
BMXCPS2000	X80 AC Power Supply Module, 100…240 V AC, 20W	Process Control/PLC	1
BMXNOC0401	M340 I/O Scanner Module, Ethernet/IP & Modbus TCP, 4 ports	Process Control/PLC	2

Table 4 shows a fragment of the specification of modules for mechanical water purification.

Table 4 – Fragment of modules for the distributed location «Mechanical cleaning»

Reference	Description of the module	Location	Quantity
STBNIP2311	STB Network Interface module, Ethernet/IP & Modbus TCP, 2 ports	Process Control/ Mechanical cleaning	1
STBPDT3100K	STB Standard Power Supply Module, 24 VDC	Process Control/ Mechanical cleaning	2
STBACO8220K	STB Standard Analog HART Output Module, 2 channels, isolated, Current	Process Control/ Mechanical cleaning	3
…	…	…	…

Table 5 contains a fragment of the equipment specification at the «Biological cleaning» stage.

Table 5 – Fragment of the modules for the distributed location «Biological cleaning» specification

Reference	Description of the module	Location	Quantity
STBNIP2311	STB Network Interface module, Ethernet/IP & Modbus TCP, 2 ports	Process Control/Biological cleaning	1
STBPDT3100K	STB Standard Power Supply Module, 24 VDC	Process Control/Biological cleaning	1
STBACO8220K	STB Standard Analog HART Output Module, 2 channels, isolated, Current	Process Control/Biological cleaning	1
TSXCDP1001	Pre-wired cable with HE10 connector at one end and flying leads at the other end – 10m	Process Control/Biological cleaning	8
…	…	…	…

The modules and accessories that will be used in the design of the chemical cleaning system are shown in Table 6.

Table 6 – Fragment of the modules for the distributed location «Chemical cleaning»

Reference	Description of the module	Location	Quantity
STBNIP2311	STB Network Interface module, Ethernet/IP & Modbus TCP, 2 ports.	Process Control/ Chemical cleaning	1
STBPDT3100K	STB Standard Power Supply Module, 24 VDC.	Process Control/ Chemical cleaning	1
ABE7CPA21	Telefast Sub-base – Analog Output – 4 channels, 2-4 isolated terminals per channel, Screw connectors.	Process Control/ Chemical cleaning	2
…	…	…	…

The most recent stage of cleaning is sludge processing. The active sludge purifies the water. Silt helps to remove trace elements, nitrogen and phosphorus compounds, and organic substances from the water. For the distributed location «Sludge processing», modules were used in the configuration of the hardware, the list of which is shown in table 7.

Table 7 – Specification fragment of modules for the distributed location «Sludge processing»

Reference	Description of the module	Location	Quantity
STBNIP2311	STB Network Interface module, Ethernet/IP & Modbus TCP, 2 ports	Process Control/ Sludge processing	1
STBPDT3100K	STB Standard Power Supply Module, 24 VDC	Process Control/ Sludge processing	2
STBACO8220K	STB Standard Analog HART Output Module, 2 channels, isolated, Current	Process Control/ Sludge processing	2
…	…	…	…

Results and discussion

The results of modeling and experiments were conducted on the basis of real industrial equipment in the laboratories of SHITI and KBTU JSC.

Development of a cascade control system for the modernization of the treatment plant system.

The control system has been developed to control the main parameters of blowers. The process control mnemonic is shown in Figure 7. The hardware includes a Modicon M340 controller and a series of Modicon 241 controllers, which control Machines 1, 2, and 3. This panel provides access to subordinate controller operations.

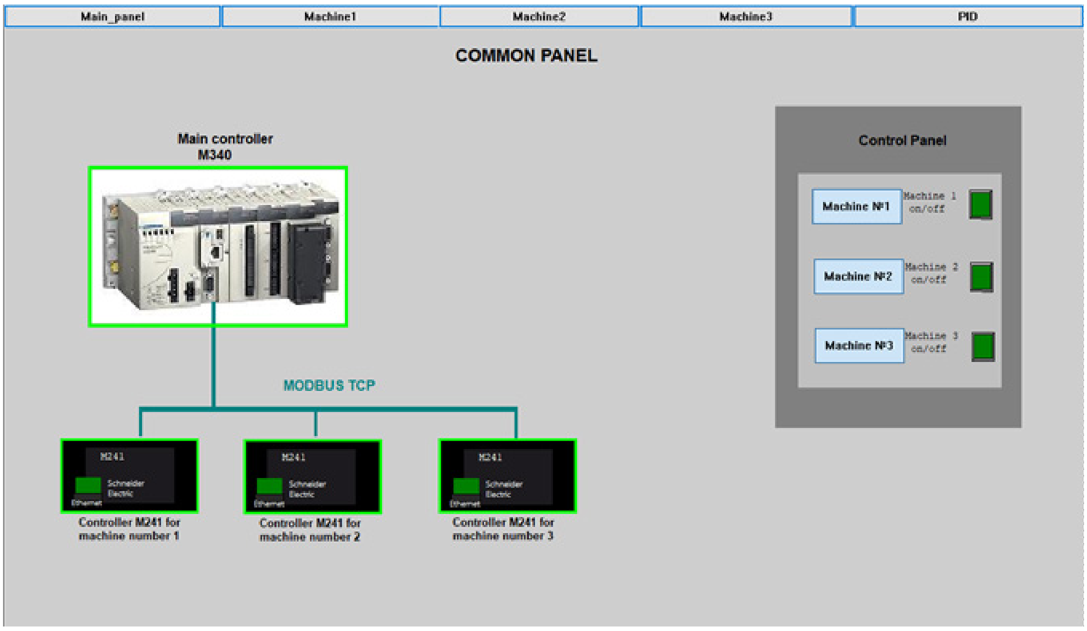

Figure 7 – Mnemonic scheme for cascade control
of the water purification process with M340 and M241 controllers

Figure 8 shows the mnemonic scheme control circuit of the blower control line. The machine is controlled by the M241 small automation controller.

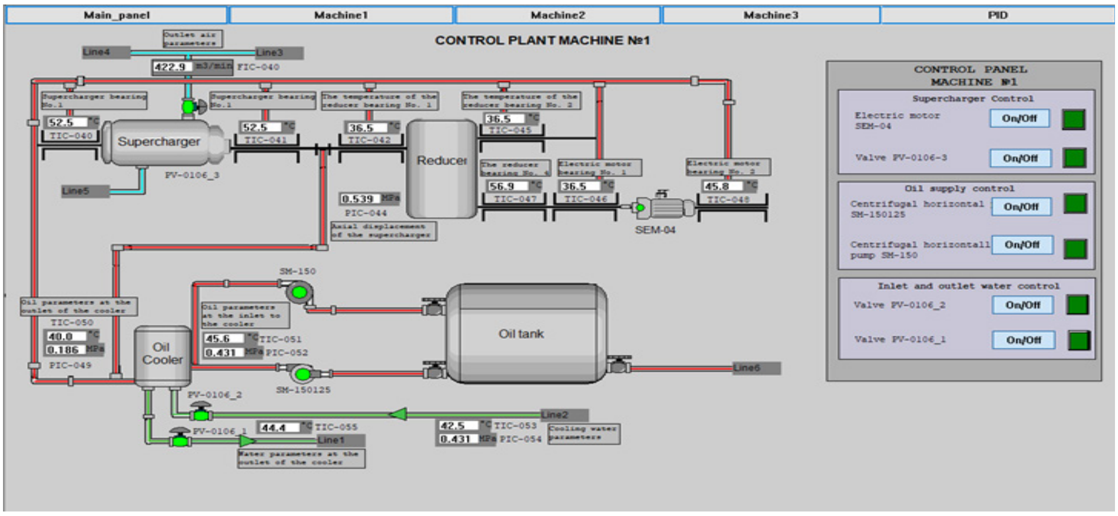

Figure 8 – Mnemonic scheme of the blower segment control system

The mnemonic scheme for controlling the lines of Machine 2, Machine 3 has an interface similar to Figure 8, Machine 1. The difference is in the names of tags and control components of the program.

Figure 9 shows a fragment of a mnemonic scheme for the implementation of the PI control system by a supercharger. The adjustment coefficients of the regulator and the main parameters of the system are shown.

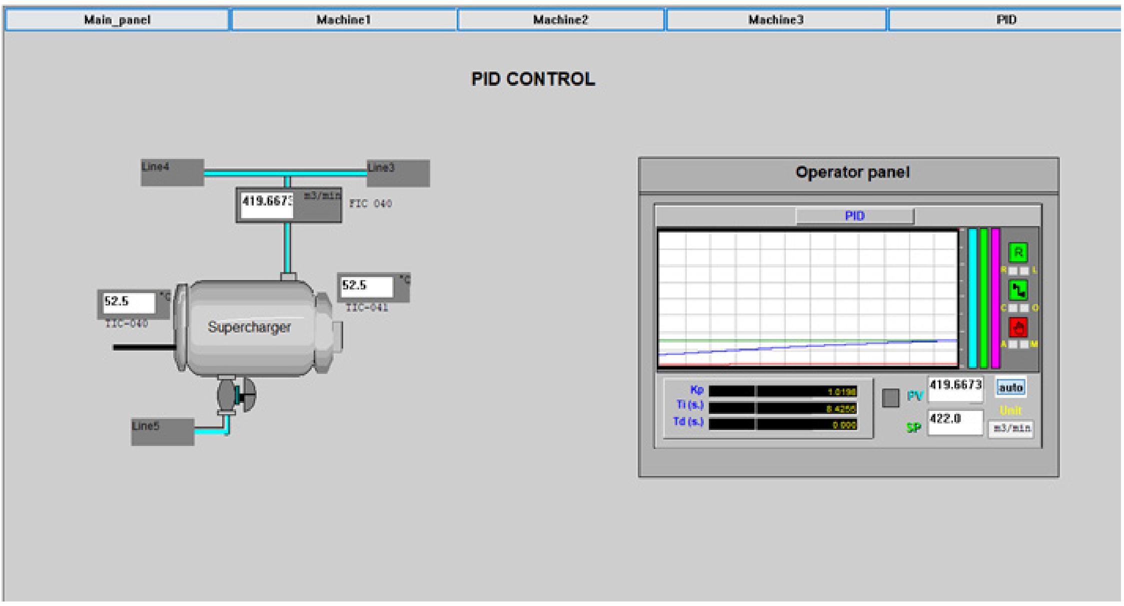

Figure 9 – Implementation of the PI regulation system in the EcoStructure Control Expert environment

The Modicon M340 controller is controlled using the EcoStructure Control Expert software product in Structured Text language. The software implementation of machine management using Modicon M241 was carried out using the EcoStructure Machine Expert software product in the LD language.

SIL calculation for a blower system at the aeration station

Special methods should be used to calculate SIL of the system. First of all, it is necessary to calculate the value of the failure rate of the system. The symbol (lambda) in reliability engineering is the value of the failure rate of a system. Failure rate is a parameter of the system that indicates the expected rate at which system failures occur per unit of time.

The average fault detection time (MTTFD) represents the idea of the effectiveness of monitoring and computing systems with respect to detected failures. The failure detection rate is similar to the failure rate [13]:

$$\lambda = \frac{1}{MTTF^{D}} \tag{4}$$

To determine the PFD^{avg} of the individual components. It is necessary to use the following formula to calculate the PFD^{avg} [13]:

$$PFD_{avg} = 1 + \frac{e^{-\lambda TI} - 1}{\lambda TI} \tag{5}$$

For the sake of simplicity, let's take the value of TI (Testing Interval) as 8760 hours from ISA-TR84.00.02-2002 – Part 3 [13].

To find the PFD of all events in a control system was used the value of PFD^{avg} via Boolean logic [13].

$$PFD = \prod_{i} PFD^{avr[i]} \tag{6}$$

$$PFD = 0.996 * 0.995 * 0.994 * 0.995 * 0.989 = 0.0969 \qquad (7)$$

RRF calculation. The Risk Reduction Factor (RRF) is used in the context of safety instrumented systems (SIS):

$$RRF = \frac{1}{PFD} \qquad (8)$$

$$RRF = \frac{1}{0.0969} = 10.32 \qquad (9)$$

Analyzing the results obtained by the RRF and PFD, it is worth concluding that the system has a SIL 1 level. The Risk Reduction Factor (RRF) for SIL 1 is in the range of 10 to 100. The PFD value for SIL 1 is between 0.1 and 0.01.

Development of an emergency protection system based on Honeywell equipment

In this work, a special concept was used to control the exhaust valve from the supercharger in order to create the safety of the blower system. The logic of «2oo3» is shown in the Figure 10 below. The «2oo3» logic demonstrates the importance of following safety measures in order to reduce the risk of failure and increase safety. If one safety measure fails, two additional measures will be applied to prevent or minimize potential harm.

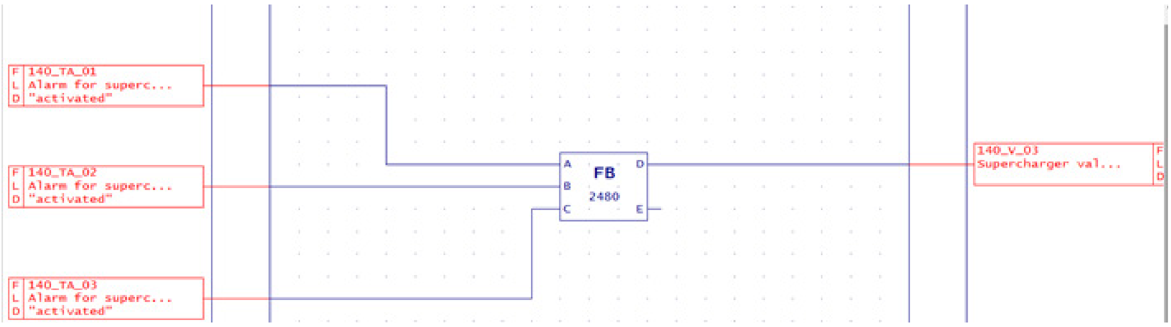

Figure 10 – Supercharger valve control by logic “2oo3”

Inputs to the system are 3 temperature indicators for the supercharger. If two of them indicate «true», it means that there are no errors, then the valve should be opened. The concept of «2 out of 3 safety» is often used in high-risk industries or situations where a single safety measure may not provide sufficient protection.

Conclusion

Modernization of automatic control systems at strategically important facilities, such as sewage treatment plants, is necessary. The state of automation affects the efficiency and functionality of the treatment plant’s system. The issue of improving automated systems is acute, particularly with an ever-growing population in cities. Reconstructing outdated control cabinets is significant. The condition of urban water supply systems has an impact on citizens’ well-being.

The article conducted research into the development of a new automated aeration system (biological cleaning station) for the Almaty Su company. At present, the operation of air blower machines on the aeration station depends on outdated control cabinets that operate on relays. During the research, a structure was created for controlling air blower machines using Schneider Electric software. A control system for the air blower machine was established, and the configuration of the network and architecture of the system were implemented.

The technological process of water purification involves a stage of biological treatment, which takes place at an aeration station. Biological treatment is impossible without the use of activated sludge, which requires oxygen. Oxygen is provided by a blower system. The basic principle of air blower systems is the use of a supercharger. Therefore, the supercharger was chosen as the subject of study. The analysis of the operation of the blower system also includes the development of a mathematical model. During this process, PI controller was designed, resulting in better performance compared to a system with or without PID controller.

For the safety of the air blower system, a safety system has been developed according to the «2oo3» logic. The safety system must prevent false operation of the compressed air supply to the air tanks.

The problem of developing and designing modernized automation systems must be solved before outdated equipment fails. Automated systems at strategically important facilities and enterprises must comply with all applicable standards and function promptly.

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SCHNEIDER ELECTRIC ӨНДІРУШІСІНІҢ ЖАБДЫҚТАРЫН ПАЙДАЛАНА ОТЫРЫП АҒЫНДЫ СУЛАРДЫ ТАЗАРТУ ҚОНДЫРҒЫЛАРЫНДАҒЫ СУДЫ ТАЗАРТУ ЖҮЙЕСІН ЖАҢАРТУ

Аңдатпа

Қазіргі уақытта сумен жабдықтау және су тазарту сияқты қаланың стратегиялық маңызды инфрақұрылымдық объектілерінде ескірген автоматты басқару жүйелерін жаңғырту өзекті мәселелердің бірі. Заманауи автоматтандыру құралдарын пайдалану экологиялық жағдайды жақсартуға және технологиялық процестің сенімділігін арттыруға мүмкіндік береді. Бұл мақалада «Алматы Су» кәсіпорнының кәріз тазарту құрылысының биологиялық тазарту станциясын автоматтандыруға арналған жаңа жүйені әзірлеу қарастырылған. Жүйені әзірлеу барысында Schneider Electric компаниясының жабдықтары, атап айтқанда, Modicon M340 сериялы контроллерді басқаруға арналған Ecostructure Control Expert бағдарламалық өнімі қолданылды. Осы құралдардың көмегімен ауа айдау машиналарын басқару жүйесі жасалды. Сондай-ақ, Modicon M241 контроллері негізінде ауа айдау машинасын басқару жүйесі Ecostructure Machine Expert бағдарламалық өнімі арқылы жобаланды. Modicon M340 және Modicon M241 контроллерлері арасындағы ақпарат алмасу негізінде процесті басқарудың мнемотехникалық схемасы әзірленді. Желі конфигурациясын жасау үшін Architecture Builder құралының көмегімен қашықтан енгізу-шығару архитектурасы жасалды. Аварияға қарсы қорғау жүйесі ретінде ҚБТУ АҚ-дағы Honeywell компаниясының жабдықтары негізінде Safety Controller және Safety Manager құралдары қолданылды. Сонымен қатар, кәсіпорындағы қауіпсіздік деңгейлері, атап айтқанда SIL деңгейлері есептелді. Бұл жаңа жүйенің енгізілуі кәріз тазарту станциясының жұмысын едәуір жақсартып, автоматтандыру деңгейін көтеруге мүмкіндік береді, бұл өз кезегінде қаланың экологиялық жағдайына оң әсер етеді.

Тірек сөздер: сумен жабдықтау, автоматика жүйесін жаңарту, айдау машинасы, үрлегіш, бағдарламаланатын логикалық контроллер.

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МОДЕРНИЗАЦИЯ СИСТЕМЫ ОЧИСТКИ ВОДЫ НА ОЧИСТНЫХ СООРУЖЕНИЯХ СТОЧНЫХ ВОД С ИСПОЛЬЗОВАНИЕМ ОБОРУДОВАНИЯ ПРОИЗВОДИТЕЛЯ SCHNEIDER ELECTRIC

Аннотация

В настоящее время является актуальным вопрос модернизации устаревших систем автоматического управления на стратегически важных объектах инфраструктуры города, таких как водоснабжение и водоочистка. Использование современных технических средств автоматики позволяет добиться улучшения экологической ситуации и повысить надежность работы технологического процесса. Статья посвящена разработке новой системы автоматизации станции биологической очистки канализационного очистного сооружения предприятия «Алматы Су» для замены текущей устаревшей автоматики. Разработана система управления воздухонагнетательными машинами на основе оборудования фирмы Schneider Electric с помощью программного продукта EcoStructure Control Expert для управления контроллером серии Modicon M340. С помощью программного продукта EcoStructure Machine Expert разработана система управления воздухонагнетательной машиной на основе контроллера Modicon M241. Спроектирована мнемосхема управления процессом с переключением между контроллерами Modicon M340 и Modicon M241. Разработана архитектура удаленного ввода–вывода с помощью инструмента Architecture Builder для создания конфигурации сети. Представлена система противоаварийной защиты на оборудовании фирмы Honeywell при АО КБТУ с использованием инструментов Safety Controller, Safety Manager. Рассчитаны уровни безопасности на предприятии – SIL.

Ключевые слова: водоснабжение, модернизация системы автоматики, нагнетательная машина, воздуходувка, программируемый логический контроллер.

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