Design of Desulfurization Wastewater Treatment Control System

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Abstract. It is very important to treat the desulphurization wastewater caused by the flue gas desulphurization process of the marine diesel engine. In this paper, the desulfurization wastewater discharged from the sodium-alkali seawater desulfurization system was studied and a desulfurization wastewater treatment control system based on Siemens PLC was designed. The monitoring system consisted of the machine side touch screen and the remote host computer. It was used to monitor the operation of the control system in real time, store system data, and display reports, curves, alarms, and other information. Furthermore, the automation of aeration, dosing, flotation, scraping, water quality monitoring, and discharge in the process of desulfurization wastewater treatment was realized by using this system.

1. Introduction

In order to meet the increasingly strict IMO regulations on the washing water discharged from the closed seawater scrubbing system with sodium alkali method of the marine diesel engine exhaust gases, it is necessary to treat the wastewater separated from the washing liquid before discharging it out of the tank [1].

In the sodium-alkali seawater desulfurization system, NaOH is used as the desulfurizer to absorb SO₂ in the flue gas of the marine diesel engine. SO₂ in the flue gas reacts with NaOH in the washing liquid inside the washing tower so as to achieve the desulfurization effect. However and in order to maintain the density of washing liquid at a certain level, part of the wastewater in the circulation system needs to be discharged out when the density of washing liquid is too high. This discharged wastewater is desulfurization wastewater, which contains emulsified oil and combustion products while its pH value is approximately neutral. Therefore, the wastewater needs to be treated before it can be discharged outside the cabin as required. The desulfurization wastewater treatment device has three control objectives including pH control, PAH control, and turbidity control, which are to ensure that the desulfurized wastewater meets the requirements of IMO washing water discharge regulations.

In order to ensure the efficiency and quality of desulfurization wastewater treatment process, this paper introduces an automatic control system to monitor the wastewater treatment process. This system mainly consists of two parts. The first part is the PLC control system which is responsible for the coordinated control of the whole system including water quality monitoring, drug configuration, communication with the host computer, and touch screen. The second part is the monitoring system of the WinCC host computer and the machine side touch screen, which provides a simple and intuitive platform for the operator to view the information of the wastewater treatment, control the process, and interact with the whole wastewater automation system.
2. System process introduction

The desulfurization wastewater treatment process is shown in Figure 1. The system mainly consists of the following parts: waste liquid buffer tank, supply pump, 1 stirring motor, 1 base pump, 2 metering pumps, air compressor, dissolved gas tank, dissolved gas pump, air flotation separation tank and scraper, filter tank, secondary buffer Tank, return pump, power pump, pH detector, turbidity detector, and PAH detector.

![Figure 1. Desulfurization wastewater treatment process](image)

The process of desulfurization waste liquid treatment system includes NaSO\(_3\) oxidation, chemical flotation, activated carbon filtration, emission detection, and other major processes.

During NaSO\(_3\) oxidation process, the wastewater discharged from the washing solution enters into the waste liquid buffer tank and is forcibly aerated through the oxidation fan in order to oxidize the desulfurization intermediate NaSO\(_3\) in the washing water and form NaSO\(_4\), which at the same time reduce the COD value in the washing water.

The oxidized wastewater enters the flotation tank and the chemical flotation process will start. The flotation tank regulates the wastewater, adjusts the pH of the wastewater, and uses a dosing pump to add coagulant and flocculant agents to the wastewater and a mixer to mix the wastewater with these agents. Then, the dissolved gas is driven to the bottom of the flotation tank and is mixed with the suspended matter, which helps to separate the suspended layer. After that, the suspended layer is collected and stored in the sludge tank by the scraping device to later transfer into the shore and achieve harmless discharge. Amongst them, the coagulant agent is used to separate the emulsion into oil and water and the flocculant agent is used to polymerize particles into fibrous materials that are easier to collect. While the pH value is adjusted by using NaOH.

In the activated carbon filtration process and before the water enters the filter, part of the water is used as a source for the dissolved air flotation while the rest is discharged through the activated carbon filter. Finally, the washing water treated by the above functional modules will be discharged if it meets the discharge standard requirements after being tested by the detection device otherwise it will be returned to the waste liquid buffer tank for re-treatment.

3. System Design

3.1 design principles

The main task of the desulfurization wastewater treatment system is to ensure the standard discharge of the treated wastewater with maintaining the stable operation of the main desulfurization system.

The design principles of the system are as follows: (1) after the wastewater from the washing tower is diverted into the wastewater treatment system, it is treated through the above process to ensure that the treated wastewater meets the requirements of IMO emission regulations. In addition, the subsystems
should be in an optimal operating state, which can save energy consumption and the amount of the agents. (2) When the operating state of the desulfurization system changes, the water quality of the washing tower shunting into the wastewater treatment system changes, and the treatment system should respond in time, eliminate interference quickly, and meet the discharge requirements of the treated wastewater.

3.2 hardware design
The hardware of the desulfurization wastewater treatment control system mainly consists of the following: Siemens industrial computer as the host computer (This computer equipped with a display, printer, keyboard, etc.), Siemens TP1200 compact touch screen, Siemens S7-1200 PLC (including power supply, CPU1214C, storage card, etc.), 3 AI8×13-bit analog quantity input modules, 1 AQ4×14-bit analog quantity output module, 1 DQ8×24V digital quantity output module, solenoid valve, sensors, etc. The sensors mainly include PH sensor, PAH sensor, turbidity sensor for monitoring water quality, pressure sensor for each pump inlet and outlet, liquid level sensor, and so on. PLC hardware configuration is shown in Figure 2.

![Figure 2. PLC hardware configuration](image)

The PLC connects the various functional blocks to the extension modules and realizes the stable operation by controlling the wastewater treatment system I/O devices.

3.3 software design
The software design of the desulfurization wastewater treatment control system mainly includes three parts: PLC program design, editing configuration of the machine side monitoring screen, and editing design of the host computer WinCC. Among them, the PLC controller function is to collect the analog sensor signal and convert it into digital quantity after processing and complete the logic control of the whole system operation including the action execution of the valve, triggering the system alarm, and other operations. In addition, HMI equipment monitoring and the host computer monitoring are mainly responsible for the real-time monitoring, display of the system operating parameters, online modification of related control parameters, and control operation in manual operation mode. Moreover, PLC, HMI and the host computer read each other's data through data transmission. In operation control, switching the operation is restricted by the program, which has a little influence on data transmission and high reliability [2].
Figure 3. Control system composition

Siemens TIA Portal software was used to write the system software as it provides a friendly environment for the user and helps to manage and configure all the equipment in the project such as the PLC, the HMI, etc. PLC control software adopts modular programming. Modular programming is to divide the program into different logic blocks according to functions, and each logic block completes different functions. In the main loop OB1, different functions or function blocks can be called in accordance with the condition, which is characterized by easy division of labor and facilitates debugging [3]. According to the desulfurization control system structure, the system adopts two tissue blocks (OB), six functional blocks (FC), and one data block (DB). The function block (FC) mainly realizes the start and stop, alarm and indication of aeration, chemical flotation, filtration, and discharge system. Furthermore, initialization of alarm signal bit, initialization of filter signal bit, initialization of fault signal bit, initialization of filter buffer, assignment of alarm upper and lower limit, and assignment of other system initial operating parameters are edited using the initialization program block OB100[4].

The PLC control system software mainly implements the following functions:

1. Collect sensor information used in the control system, calculate the collected data, and convert it to the floating point data type required by the host computer display.
2. Set all the control information and the solenoid valve feedback information of the control system.
3. Control all executable equipment on site including the oxidation fan, the mixer, the metering pump, the supply pump, the solenoid valve, the slag scraping equipment, etc.
4. Calculate the amount of drug to be added by detecting the PH, the PAH, and the turbidity of the water after oxidation in the buffer tank.
5. Detect the operating status of the system and send status and alarm information to the host computer to drive the corresponding indicator light and buzzer, etc.

The design of the desulfurization wastewater treatment control system is not only about developing the software of the system but also includes the editing and design of the monitoring interface. During the process of control, the controller exchanges data with the monitoring system to realize the real-time control and the parameter monitoring of the entire wastewater treatment system. The desulfurization wastewater treatment control system is divided into machine-side HMI equipment and remote PC monitoring. According to the actual operation of the wastewater treatment system for sulfur removal, the control screen should have perfect functions such as the simplicity and convenience in the control process, the ease to understand the screen parameters, and the ability to prevent operating errors. Based
on the principles mentioned above, the design of the monitoring system is divided into the user rights management, system process flow screen, the manual operation, the system monitoring and alarm parameters, the history data archiving, and the related auxiliary interfaces. Furthermore, the monitoring system can realize debugging to modify the parameters in the control system. The design of the monitoring system of the overall block diagram is shown in Figure 4 below.

![Monitoring system structure](image)

**Figure 4. Monitoring system structure**

The monitoring interface of HMI equipment is developed by TIA Botu software, integrated with the PLC program, and placed on the control cabinet for the machine side monitoring of the system. Besides, siemens touch screen is adopted to make the operation simple and convenient. The host computer monitoring system is developed based on WINCC platform, which is used for remote monitoring operation on the computer. The design and development of the two systems have great similarity in the process monitoring and the operation function of the system but there is a limitation in the operation control. Both manual operation and automatic operation can be realized on both interfaces but can only be implemented on one interface at a time, which can ensure the safety and the stability of the system.

Switching the operation between the touch screen and the host computer is realized on the control cabinet. The manual/automatic switching of the touch screen operation is performed on the control cabinet while the manual/automatic switching of the host computer can be realized on the host computer.

The operating status of the control system of the desulfurization wastewater treatment system and the various monitoring signals are displayed on the computer display and the touch screen on the machine side after compiling the data through configuration software. Each button on the system schematic diagram on the display screen is responsible for controlling the opening and closing of the metering pump, the slag scraper, the air compressor, and the dissolved air pump, displaying the liquid level of buffer tank, and checking whether the PAH, the turbidity, and the pH in the wastewater at the outlet of the desulfurization system can meet the discharge standards.

The control system monitors more than 30 faults and the local human-machine interaction equipment of the system directly reflects the real-time fault and checks the historical fault records. Besides, the control system reports the equipment fault to the host computer in real-time which in turn determines the fault handling mode.

### 3.4 communication design of the control system

The communication scheme of the desulfurization wastewater treatment control system is based on Siemens Ethernet communication. Industrial Ethernet provides the industrial Ethernet standard for process control field communication equipment. Through the exchange of Ethernet structure, data transmission has better security and stability and the transmission speed is fast. Therefore, the industrial Ethernet communication technology has been widely applied and developed in the industrial field. Siemens industrial Ethernet can support different communication protocols such as TCP, ISO, S7 basic communication, etc. These protocols make the connection between communication equipment very convenient and the transmission medium is usually coaxial cable, shielded twisted pair, or optical fiber. Thus, communication with devices such as controllers, PLCs, measuring transducers, actuators, and
other equipment communication has become an efficient solution. In this paper, the industrial Ethernet communication based on S7 protocol mainly completes the communication of the control system of the desulfurization wastewater, the Ethernet communication of TCP/IP protocol, the CPU control program debugging download, and the host computer control [5].

The TCP/IP protocol is based on data stream communication but does not encapsulate the data as a message block. The user does not need to receive the acknowledgment signal of each task. Moreover, the transmission and reception of the protocol make the communication between the devices based on the TCP/IP protocol very common.

The Ethernet interface of the control system is selected from the industrial Ethernet switch module model SCALANCE XB004 with 4 industrial Ethernet ports, which is a plug-and-play device that does not require any setup during debugging. It can automatically determine the transmission speed and transmission mode of the partner port through the auto-negotiation mechanism, the repeater, and the terminal device. Thereby, various devices are automatically configured by using it. The communication connection of the control system is shown in Figure 5.

![Communication connection of control system](image)

4. Conclusion
The desulfurization wastewater treatment control system based on Siemens PLC has the characteristics of reliable operation and superior control performance. At the same time, the monitoring system composed of touch screen and upper computer monitors the running state of the system in real time so that the operator can find out the system fault in time and obtain a good monitoring effect. The system has been successfully used in the wastewater treatment of Marine diesel engine exhaust sodium alkali desulfurization system, which realizes the automation of desulfurization wastewater treatment, reduces the impact of wastewater discharge on the marine environment, and achieves good economic and environmental benefits.

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