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Simulation of reverse osmosis seawater desalination system based on virtual reality technology

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ABSTRACT

In this paper, the seawater desalination system of Huangdao thermal power plant was taken as the research object, and a virtual reality system for seawater desalination was developed for personnel training. The system test results showed that the system can simulate the process of desalination and the process of equipment use. It can reproduce all kinds of states of seawater desalination system, and can be used to train the managerial staff of seawater desalination system.

Keywords: Reverse osmosis seawater desalination system; Virtual reality; Analogue simulation

1. Introduction

Water is an indispensable natural resource for the survival and development of human beings. It is accounted for 75% of the total surface area, among which 97.5% is sea water, only 2.5% is fresh water, while ice caps and glaciers contain 75% of the world's freshwater, and almost all of the rest are buried deep underground, or exist in the form of wet layer or permafrost layer. Rivers and lakes are accounted for only 0.3% of fresh water on the earth. Only less than 1% of the surface water or underground water is used for human beings [1]. With the rapid growth of social economic development and population, human demand for water is increasing rapidly, agricultural production and industrial production, as well as urban life can cause water pollution. And all these facts are causing the freshwater resource decreasing sharply, so that the whole world is facing a serious shortage of freshwater resources.

For many years, in order to alleviate the crisis brought by the lack of water resources, many countries have set up specialized agencies, which had invested a lot of manpower and material resources to research and develop seawater desalination technology. So far, the commonly used methods of seawater desalination are as follows: distillation, crystallization, electro dialysis, reverse osmosis (RO), ion exchange and so on [2]. Among them, the RO desalination technology has made rapid development in recent years, and both membrane and module production had been quite mature. In 1990s, the low pressure membrane industrialized production made the RO technology become the most economical means for the preparation of desalination of sea water, desalination of brackish water, pure water and ultra pure water [3]. At present, the seawater desalination by RO has occupied 88% of the world sea water desalination market, which has been widely used by the seawater desalination project both at home and abroad. With the rapid development of computer control and automatic detection technology, the distributed control system (DCS) has been widely used in the process of industrial production [3]. The automation of the industrial process has been continuously improved, which makes the requirements on the operators become higher and higher. Therefore, it is particularly necessary to strengthen the training work of RO seawater desalination system

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operators, so as to improve their technical level in industrial production and deal with complex working conditions. The simulation system based on computer simulation technology can effectively make up the shortage of traditional teaching and training, which can help operators to be familiar with the operation process of the whole seawater desalination plant, so as to train operators to analyze the operation data of the system and deal with the unexpected failures.

The ultimate purpose of developing the simulation training system is to save money on the basis of ensuring the training quality, and to improve the operator skills and accident response ability effectively. If the cost of the simulation training system exceeds the benefits that it can bring, then it will lose its meaning. In the current design of the simulator, it is more realistic to let the simulator replace some of the training teachers, such as automatic grading, automatic analysis of the quality of the operation process, automatic recording of the operation steps and realization of the automatic reproduction of the operation process, etc.

The aim of this paper is to design a simulation system that can be used for training operators of RO seawater desalination plant. The operator can operate on the simulated computer monitor screen. A kiloton seawater desalination system of Huangdao Power Plant, Shandong Province is taken as the research sample. Through analysis on the working process and mechanisms of the system, a RO seawater desalination system is established by using virtual reality technology [4,5]. Through a good user interface, the trainers' training and assessment of the trainees can be realized, so that the engineers and technicians can have a better understanding of the production process and the professional theoretical knowledge.

2. Principle analysis of reverse osmosis seawater desalination

RO is a separation technology, taking pressure as the driven power by using semi-permeable membrane perm selectivity, by means of impurity in the water to be removed by the membrane, which has the advantages of simple operation and low power consumption. Membrane separation technology is to exert pressure on the concentrated solution on the side of the membrane. When the pressure exceeds its osmotic pressure, the solvent will conduct RO against the direction of natural infiltration, so that the fresh water will be left at the low pressure of the membrane and the concentrated seawater will be left on the high pressure side (Fig. 1) [6].

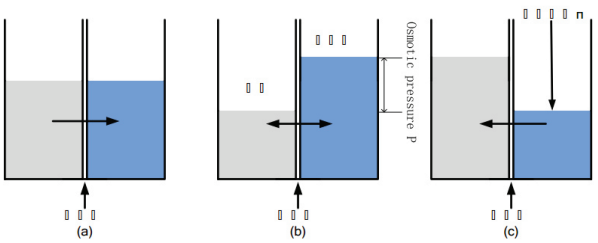

Fig. 1. Working principle of reverse osmosis seawater desalination system.

3. Technological process

In this paper, the basis of designing the virtual reality system is on the demand to develop for 10,000 tons/d RO seawater desalination plant according to the demand of seawater desalination project in Huangdao Power Plant, Shandong. The process flow of this system is shown in Fig. 2.

4. Realization of virtual environment for reverse osmosis seawater desalination system

This simulation equipment of the system is mainly composed of the integrated operator station, the central processor, the host of the teacher's machine, as well as the host for performing the three-dimensional simulation modeling of the seawater desalination device. In addition to the two host computers, there are projectors, curtain and some other auxiliary hardware facilities, and the operating staff mainly operates the host computer. The hardware structure of this system is shown in Fig. 3 [7,8].

The hardware is the basis of the simulation system, and the software is mainly composed of two parts: system supporting software and function software. Among them, the system supporting software is provided by the relevant manufacturers, while the function software is mainly responsible for all the functions of the simulation system, which is specially developed according to different production processes.

The functions of simulation system can be divided into system supporting software and system function software according to functions, which is composed of the related model modules and functional modules. And the data area inside the system can be shared by modules. The system support software is provided by the hardware manufacturer of the simulation system. The simulation system function software is developed for different production processes and specific systems, which can complete all the functions of the simulation system (Fig. 3).

Software module can be divided into the following parts:

1. Task scheduling module: This module mainly includes function key module, data management module and display module. They are mainly used to schedule and manage every task that is needed in the simulation process. Because these tasks are relatively independent and need to use common data, the task scheduling module is similar to a master program to coordinate the work of the whole software.
   - Function key management: operators using the operation interface of the system will input the related command into the simulation system, then the system gets the results through the calculation of the model and it can reflect it on the large screen display.
   - Display management: operator can have a more intuitive understanding by displaying the running state of the system management, because it can put the data through the projection screen or cathode ray tube output directly, which also can adjust the system input timely; on one hand, display management can realize by copying the actual implementation of DCS, on the other hand, through LabVIEW control

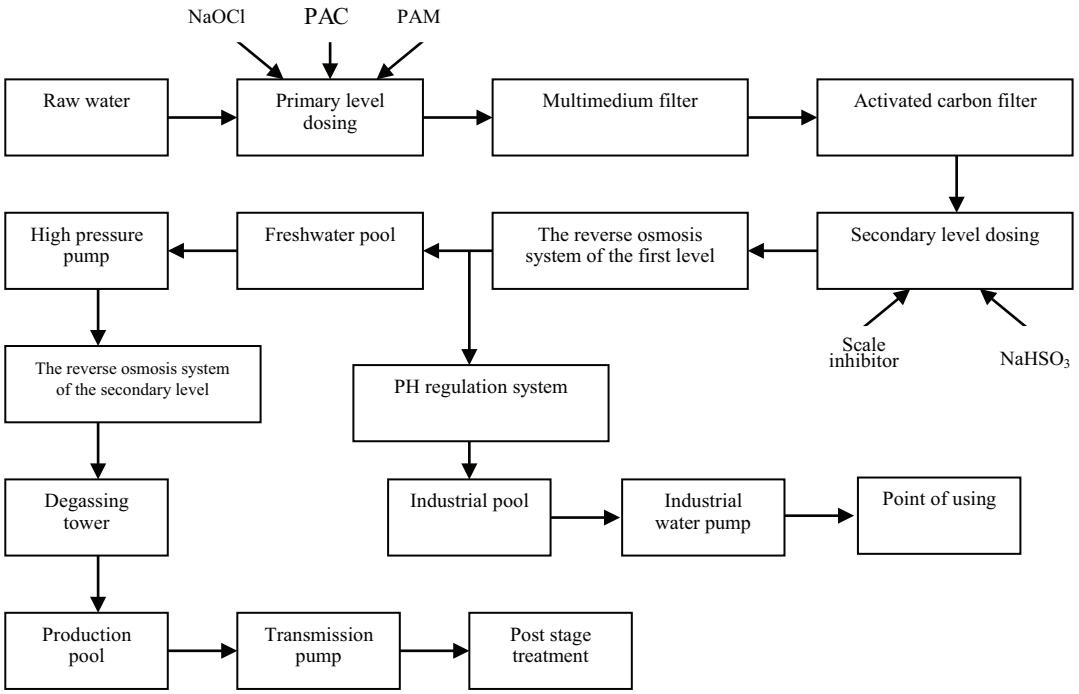

Fig. 2. Process flow of reverse osmosis seawater desalination system.

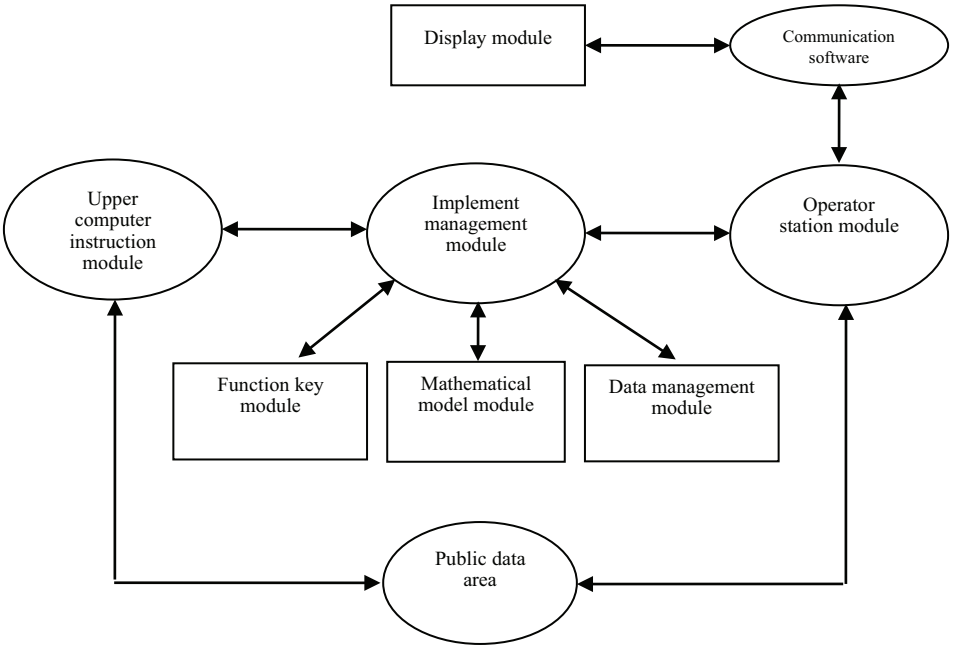

Fig. 3. Structure of software module.

technology, it can develop and use the dynamic elements such as bar chart, status indicator and alarm sequence display, switch operation, curve, analog controller, analog display, eventually forming a more intuitive interface.

- Data management: the model input can reflect the students' operating result, input file data, PC input data, both the input and output data can operate according to a certain mode of operation, through data processing form, it can be transformed into the available model form; therefore, the mathematical model is the core of the simulation system (Table 1).

2. Upper computer instruction module: the main function of this module is to start and run the simulation system,

Table 1
Biofidelity analysis of the system test results

Test projects	Actual processing schemes	Comparison of test results with real state	Validity	Discussion
Operation process of seawater desalination system	Actual seawater desalination system workflow	True reproduction of the entire simulation process	96.3%	The software can reproduce the whole process of seawater desalination system, and the 3D model with high fidelity also has room for improvement.
Salt penetration rate increases, the water yield decreases, and the pressure difference between each segment increases, and the quality of membrane module increases significantly.	Metal oxide pollutions: • Analysis of daily SDI test membrane retention substances • Analysis of metal ions in cleaning solution • Dissection and analysis of contaminated membrane elements • Cleaning of metal oxide pollutants • Improvement of pretreatment process and operation conditions Colloid contamination • Analysis of daily SDI test membrane retention substances • Dissection and analysis of contaminated membrane elements • Cleaning with grease detergent • Improvement of pretreatment process and operation conditions Dirt of inorganic salt • Checking the Langelier saturation index (LSI) of the concentrated water system and the solubility product test of the insoluble matter likely to be generated • Dissection and analysis of typical contaminated membrane elements • Selecting appropriate cleaning agents for specific conditions • Selection and application of more effective scale inhibition or dispersing agents • Improving pretreatment system Sludge pollution • Detection of influent NTU after pretreatment system • Dissection and analysis of typical contaminated membrane elements • Improving pretreatment system • Cleaning with HF and colloid cleaning solution	Three possible pollutant treatment schemes were simulated. Three kinds of pollutant treatment schemes and operation processes were described in detail through 3D demonstration.	93.7%	The simulation system can reproduce the fault principle and solution of seawater desalination treatment system. 3D model operation process was described in detail. More description of the methods to prevent failures should also be added.
Salt permeability and water yield increases but the pressure difference between influent and concentrated water is normal.	Organic pollution • Disconnecting of membrane assemblies (pressure vessel), checking of reverse osmosis membrane component contamination at inlet end • Water quality analysis of raw water and concentrated water • Cleaning solution for cleaning the system with alkaline cleaning solution • Improving system pretreatment process	The organic pollutants and their treatment methods were simulated in 3D, and the organic pollutants and their measures were simulated.	95.4%	The simulation system tests demonstrated the cause of the fault and the way to deal with it. The system transformation should be further explained.

(*Continued*)

Table 1 (*Continued*)

Test projects	Actual processing schemes	Comparison of test results with real state	Validity	Discussion
In the initial, salt transmittance is constant or even decreases. After running for a period of time, the salt transmittance of the system begins to increase. At the same time, the pressure difference between the influent and the concentrated water increases and the water production of the system decreases.	Biological contamination • Taking apart the membrane assembly and checking the pollution symptom at the inlet end of the membrane element • Analysis of biological and bacterial indexes of concentrated water and product water in reverse osmosis system • Performing of first cleaning process with alkaline cleaning solution, and then using the allowed sterilizing cleaning agent to prepare the cleaning liquid cleaning membrane system • Improving system pretreatment process	The process principle and consequence of biological pollution are demonstrated, and the treatment process is simulated.	93.8%	The simulation system can simulate the operation process well and simulate the normal processing process when the operating system encounters this problem. However, the proportion of cleaning liquid should be described in further detail.
The salt permeability increases, the water yield increases and the pressure difference decreases.	• Membrane surface is scored by particulate matter in water supply or inorganic scaling crystals formed by system concentration polarization. • Particulate pollutant • Analyzing of the last stage of inorganic salt fouling, checking of the LSI value of the concentrated water, and testing of the solubility product of the insoluble substance • Improving of pretreatment system • Adjusting of the water recovery rate of the system • The first stage water production of RO system is reduced, and the deposition of particulate pollutants occurs if a more effective scale inhibitor/dispersant is used	The relationship between the damage degree of the membrane surface and the reduction of the pressure difference was simulated.	85.7%	The damage mechanism and treatment method of membrane surface are introduced. But only the processing scheme was simulated. The processing steps need to be explained in detail.
The salt permeability increases, the water yield increases and the pressure difference decreases.	• The salt passing rate and water yield increases, and the pressure between influent and concentrated water decreases or be normal • Reverse osmosis membrane is oxidized by oxidizing substances input water, which results in degradation of membrane performance • Monitor the water quality and quantity of the first reverse osmosis membrane assembly, the test values were standardized and compared with the data reported by the test machine • For the more serious cases, it is necessary to selectively replace the degraded membrane elements • Improving system pretreatment process • Add monitor of redox potential (ORP)	Simulate the system countermeasure and processing scheme when the pressure decreases.	98.4%	The causes of pressure difference reduction and the treatment scheme are introduced. The process of membrane replacement was simulated in detail.

select the display process flow screen, manage the operation of the module and set up training contents. In practical applications, we can choose the required training projects by setting initial conditions, displaying the operation process of the system, training subjects as well as setting up faults.

3. Operator module: the operators can adjust the given value of the controller by using mouse and keyboard operation, so as to change the state of starting valve and closing valve, as well as the pump and pneumatic control valve through the module. The module can provide the corresponding interfaces according to different environments, which can directly switch simulation software, control system and its function blocks, as well as work state of composite blocks and historical libraries.
4. Mathematical model module: after the simulation starts, the module is responsible for adjusting the input data of the relevant modules, and manage the modules according to the relevant requirements of the mathematical model module, then it adjusts and arranges the continuous cycle of simulation. It can be seen that this module is the core of the whole computer simulation software system.
5. Communication module: we develop the corresponding communication modules according to the function and characteristics of DCS simulation system, among them, the real-time performance and the accuracy of receiving data are our first consideration. When DCS simulation system is operating, each sampling period of communication includes data transmission in two directions, which can, respectively, provide DCS simulation operation condition data, and also the three on-site operation station data. Its essence of communication process is a cycle that is controlled by a sampling clock [9].

In this simulation system, our 3D software is written by C language, so we need to choose TCP/IP as a network protocol to realize the need of interconnection. In view of the complexity of the protocol, LabVIEW provides the user with a packaged Vl function, which can greatly simplify the programming of the communication protocol [10].

5. Operation and measurement of the simulation system

5.1. Overall operating test

Click the flow chart of the main operating area of "operate", "stop", "quit" button, and observe whether the system is normally starting, operating, stopping, quitting, as well as the states of the other functions, checking out whether the operation parameters and steady state data of the simulation system is consistent with the testing data on spot.

After the "operate" button is pressed in operation area, each objects of the process interface is turning activates, system can operate according to the process continuously, after the dynamic regulating process in 1 min or so, the instrument parameters of numerical process interface are basically stable, without external interference, under the condition that the setting value remains unchanged, the whole simulation system can go into a stable state.

5.2. Fault setting and warning information display function test

Fault setting and warning information display function test mainly checks the fault status setting function of the system, as well as whether the operation parameter of the fault condition is implemented. The main steps of testing are as follows:

1. Running simulation system, when the system works in a stable state, click the "fault spring" button to set up the state of the related rescue state.
2. Return to the main interface of the flow chart, observe the dynamic elements of the flow chart and the trend of H change of the instrument value to see whether it can meet the requirement of the and the characteristic of the failure or not.
3. Observe whether the alarm information window under the fault running state will prompt the alarm information in time for the monitoring variables, which exceed the warning threshold or not.
4. After clearing the fault setting, observe whether the main interface elements, the instrument value and the alarm window of the flow chart, are restored to the normal state or not.

Taking the test of "RO intermediate pump failure" as an example, click the "confirm" button, when it selects the item of zero failure at the interface of setting failure, the main interface of the flow chart and the alarm information window. After setting the fault, RO intermediate pump stops working. And this can result in two-stage RO equipment stop working, while the level of RO water tank continues to rise due to RO middle water pump stopped. The high alarm information window can offer three monitoring variable alarm that is beyond the limited threshold value, which can result in the real-time alarm.

6. Results and discussion

Through the system function test and reliability test, it is found that the system can simulate the real RO seawater desalination system with high fidelity, and can reflect the real work flow and state of the seawater desalination system. The test results are reliable. The system can also effectively simulate the possible failures or special conditions that may occur in the operation of seawater desalination equipment, provide participants with a high level of authenticity and reducibility in the training environment, and meet the needs of the trained operators in mastering the equipment and the operating state of the system. And the system can also meet the training requirements in operation, problem assessment, analysis and correct handling. The system was put into operation in June 2017 and the training of the first batch of personnel was completed. The result feedback is good and meets the requirement of system design. The functions of the system were tested, and the following conclusions were drawn from the evaluation of the system tests by 20 desalination experts.

7. Conclusion

In this paper, the working principle and operation process of 10,000 tons RO seawater desalination project are

analyzed by systematic method, and the corresponding simulation system has been developed for teaching demonstration and technical training for operators. The test results show us that this system can be used for system management training of RO desalination, the integration preliminary implementation of software function module, complete the software development of operator station of the entire simulation system, which also can realize the graphical process dynamic display, normal operation, shutdown, the setting of the control function parameter, the state of fault setting, the display of warning information, as well as real-time data communication and so on.

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