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The Virtual Simulation Experiment of Chloroacetic Acid Production Process Helps Students Improve Comprehensive Ability

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Abstract

The integration of information technology and education promotes the wide application of virtual simulation experiment in teaching activities. The 3D virtual simulation experiment of chloroacetic acid production process is set based on the preparation, separation and tail gas recovery of chloroacetic acid. This project integrates the basic chemical theory, chemical unit operation, typical chemical equipment principles and operations into two parts: cognition practice and production practice. The paper gives a detail description about the construction and implementation of virtual simulation experiment of chloroacetic acid production process in chemical engineering experiment teaching. It can not only help students apply the chemical unit operation and corresponding equipment to chemical production, but also review the basic chemistry theories such as reaction mechanism, reaction kinetics and thermodynamics. A teaching model based on students' self-directed learning and teacher guidance is adopted, and the quality management and evaluation can be accurate to before, in and after class through simulation software platform. Application of this system has proved that the virtual simulation experiment teaching cannot only help students master the application of momentum transport, energy transport, quality transport, reaction engineering chemical engineering unit operations and the corresponding typical equipment, but also provides a powerful guarantee for students to effectively combine them with practice, and cultivates the safety production consciousness.

Keywords: Virtual simulation experiment; Chloroacetic acid; Congnition practice/Production practice; Chemical engineering experimental; Leading teaching mode; Performance evaluation system.

1. Introduction

Fundamental of chemical engineering is an important engineering fundamental professional cause for chemistry and related majors. It investigates chemical engineering principles and equipment of chemical engineering unit operations involved in industrial processes [1, 2], and it also acts as a bridge of chemical engineering theory and industry production. Chemical engineering experiment is an important part of practical teaching [3, 4]. However, the set experimental projects, such as measurements of centrifugal pumps, heat transfer, filtration, rectification, absorption, are usually isolated unit operation due to the limitations of teaching venues, equipment costs, and experimental safety [5, 6]. Therefore, students cannot gain the synthesis training of unit operations just like in the chemical industry. At the same time, the comprehensive ability to master chemical process and chemical production technology cannot be cultivated. Virtual simulation technology can make up for the blank of experiments that the lab can't achieve [7], and virtual simulation experiment is an important measure to promote the integration of modern information technology into experimental teaching, expand the breadth and depth of teaching content, extend the time and space of teaching and learning, and improve the teaching quality [8, 9]. Chloroacetic acid is an important chemical intermediate. Its technological process involves chemical engineering unit operations of fluid flow and transport, heat transfer, quality transport and chemical reaction. However, sulfur, liquid chlorine/chlorine and chloroacetic acid are flammable, explosive and virulent. Therefore, the preparation of chloroacetic acid is not suitable for setting in the form of physical experiments. It is because of the complex equipment, high material consumption, flammability, toxic and other issues, the virtual simulation experiment project of chloroacetic acid was developed based on the combination of virtual and reality. This reliable, safe and economical experimental project can consolidate students' chemical engineering knowledge and effectively combine it with practice.

2. Platform Design of Chloroacetic Acid Virtual Simulation Experiment

Chloroacetic acid is an important fine chemical intermediate. There are more than one hundred manufacturers in China alone. Preparation of chloroacetic acid from acetic acid and liquid chlorine under sulfur catalysis is an economical synthetic route. Especially, the process covers various chemical engineering unit operations such as fluid flow and transport (momentum transfer), heat transfer (energy transport), chemical reaction (reaction engineering), crystallization, filtration, absorption (quality transport), as well as the measurement and control of thermal parameters such as temperature, pressure, flow and level. Because the raw materials and product are flammable (sulfur catalyst), explosive and highly toxic (liquid chlorine, chloroacetic acid), it is not suitable to carry out physical experiment in teaching. At the same time, it is not appropriate to arrange production practices in consideration of

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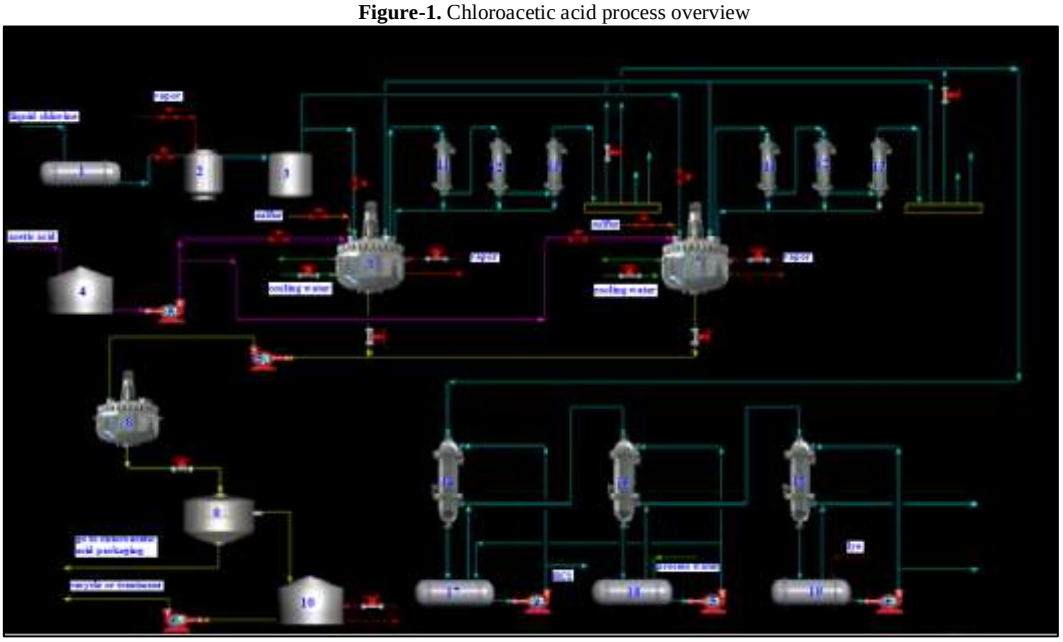
production safety. Based on the real synthesis technology coming from certain Chemical Ltd, the chloroacetic acid virtual simulation experiment soft was developed to meet the training requirements. And now, the project has been recognized as the National virtual simulation experiment teaching project of chemistry in 2018 [10].

The chloroacetic acid virtual simulation experiment software included two major parts of congnition practice and production practice. The congnition practice mainly introduced chloroacetic acid production process, chemical engineering unit operations and the corresponding equipment, material properties and safety knowledge. Following the process guidance, students can study reaction principle between chlorine and acetic acid, technological process (see Figure 1, including acetic acid charging, liquid chlorine vaporization, reaction, chlorination liquid cooling, centrifugal filtration separation, product packing, reaction gas condensation recovery, tail gas absorption and hydrochloric acid preparation), typical equipment (centrifugal pump, heat exchanger, reaction still, centrifuge, absorption tower and storage tank), proper usage of liquid chlorine, chloroacetic acid, sulfur and their toxicosis emergency treatments, instructions for safe production and so on. During the production practice, it is required to complete the feeding of acetic acid, the vaporization and feeding of liquid chlorine, and the adjustment and control of technological parameters of chlorine flow, reactor temperature and pressure. According to the instructions, students can carry out operation either in 2D or 3D interface. The operator is required to understand the changing characteristics and control requirements of reaction temperature, pressure, chloroacetic acid content and other parameters, and adjust the parameters in real time by observing the changes and feedbacks of various parameters in the simulation system. The teacher workstation will give the grade in real time. At the same time, to ensure learning effect, the platform not only embed test questions in the software, but also set questions in fore exercise for checking the self-study effect, and the summary examination questions after the experiment. To ensure the above functions are implemented, the teacher workstation management software and high-configuration computers (main frequency: not lower than 8 cores 3.6 Ghz; memory: not lower than 32 GB; storage capacity: more than 10 TB) and internet (20 M or above) need to be installed on the platform.

Figure-1. Chloroacetic acid process overview



1. liquid chlorine tank; 2. vaporizer; 3. buffer tank; 4. acetic acid tank; 5. pump; 6. the main reaction still; 7. the side reaction still; 8. crystallizer; 9. centrifugal machine; 10. mother liquor tank; 11. 12. 13. heat exchanger; 14. the main absorption tower; 15. the side absorption tower; 16. the lye absorption tower; 17. 18. 19. absorption liquid tanks

3. The Implementation Measures of Chloroacetic Acid Virtual Simulation Experiment

3.1. Adopting a Teaching Mode Based on Student Self-Learning and Teacher-Led

In the teaching of chloroacetic acid virtual simulation experiment, students independent study is the main task and the instructor only plays a leading role. Before class, the instructors prepare the study materials for students, which will appear on the virtual simulation software platform at least two weeks before the cause. At the same time, students are required to complete required learning projects before class. In class, instructor guide students to understand: the possible methods to prepare chloroacetic acid; the main reaction and side reaction between acetic acid and chlorine under the catalysis of sulfur; reaction heat and how to control the reaction temperature; how to get the solid product of chloroacetic acid; the including chemical engineering unit operations and the corresponding equipment; how to recycle the gas products and obtain hydrochloric acid. The teaching contents are organized and implemented according to the method listed in Table 1. Basing on the network platform, the instructors and students should complete the related tasks before, during and after class. This is conducive to students' independent study and comprehensive application of knowledge.

Table-1. Implementation plan of chloroacetic acid virtual simulation experiment

Roles	Before class	In class	After class
Instructors	Preparing teaching materials	Explaining the key knowledge and difficulties	Comprehensive evaluation and feedback
	Designing the teaching contents	Leading learning goals	Summary and reflection of the teaching process
	Setting up a teaching scene	Set learning tasks	
	Evaluation students' preview effect	Solve problems and improve	
	Preparing the teaching contents		
Students	Understand the learning task	Design operation plan	Complete the summary test
	Learning specified materials	Independent simulation experiment operation	Finish the experiment report
	Pre-test	Complete the setup task	Exchange learning experience
		Collaborative research and improvement	

3.2. Adopting a Reasonable Evaluation System

In the teaching of this virtual simulation experiment, the teaching management and evaluation can be accurate to before, in and after class, which overcomes the shortcomings of traditional experimental teaching. Before class, in order to enable students to master the knowledge in the classroom, they are asked to familiar with the related knowledge about chloroacetic acid production process, and complete the pre-study questions through the landing online virtual simulation software platform. As for the instructors, they can not only know the student's learning situation through the platform, but also urge the students whose pre-study score below 80 to strengthen the pre-class preparation. The preview scores will be counted into the final experimental score by 12%. In class, the instructor will focus on key points and explanation for weaknesses collected from pre-examination test. The teaching mode based on student self-learning and teacher-led is adapted. Through the interactive learning, students can get a deep understanding of what they have learned. At the same time, they need to complete the tasks embedded in the software, and the evaluation system will objectively score their operations. The operation scores are included in the final score by 36%. After class, students are required to online complete the summary test within the specified time, and the score will be included in the final score by 12%. Finally, they should submit the experiment report and exchange learning experience. The experimental report score is included in the final score by 40%. The relationship between the total score and the individual score is showed in Table 2.

Table-2. The relationship between the total score and the individual score

Items	Pre-study	Software operation	Summary test	Experimental report	Total score
Coefficient/%	12	36	12	40	100

3.3. Define Course Objectives and Leading the Learning Process

It is different from the common unit operation experiment. The purpose of virtual simulation experiment of chloroacetic acid process is to consolidate knowledge of chemical reaction, chemical engineering unit operations and equipment, and to cultivate students' ability to apply basic theories in process organization, process parameter determination and control. In order to prevent students from having a smattering of knowledge about the technological process and then imitate mechanically according to the operation manual, before the simulation operation, instructor would guide the students to analyze the reaction principle, physical and chemical properties of raw materials and products, process composition, unit operations. Finally, students can master the basic composition of the production process according to the reaction characteristics. For examples: as for the reaction principle, guides students to grasp the reaction mechanism and catalyst function. As for the technological process, leads students to understand process flow setting based on the reaction mechanism: Why the jacket of the chlorination reactor should be connected not only to the steam pipe, but also to the cooling water circulation system, and it is necessary to install a split control valve on the connecting line. Why the exhaust gas exported from the chlorination reactor needs to be cooled, congealed, recycled, and the noncondensable gas needs to be further purified through the absorption devices. As for processing equipment, guides students to associate liquid chlorine carburetor with jacket heat exchanger; the chlorination reactor is a typical stirred reactor. In order to strengthen students' mastery of reaction principle, process flow, unit operation equipment, parameter control, plane and elevation layout of the plant, production safety and correct operation, these knowledge are interspersed in the form of test questions in the pre-test, simulation operation, and summary exams.

3.4. Strengthen Software Operation, Cultivate Students' Technological Process Ability and Engineering Cognition

In class, students were required to operate the software independently. In the training of cognition practice, they should master the reaction principle, process flow, unit operation equipment, plant layout of plane and elevation, production safety. Videos, flash animations and texts that reflect relevant knowledge were inserted as showed in Figure 2. In the production practice, the learners should accomplish acetic acid feed, liquid chlorine vaporization and feed, chlorination reaction, and product crystal and separation, which would assess their ability of experimental operation, parameter adjustment and control, and increase the understanding of the dynamic characteristics of process parameter control systems. Those operations can not only perform in the 3D interface in accordance with the task guidance, and can also perform on the 2D interface of distributed control system (DCS). Simulation technology was used to simulate a complex system model revealing the intrinsic relationship and dynamic change between liquid chlorine vaporizer temperature, chlorine buffer tank pressure, chlorination reactor temperature and pressure. Through the integrated platform management system, instructors could observe the parameter adjustment and control process of each classmate. At the same time, the background program would give the score according to the operator's parameter adjustment, control stability and accuracy. The software operation scores were included in the final score by 36%. Through this operation, the students' operational ability, comprehensive analysis ability and parameter change predictive ability were cultivated. At the same time, it also made them aware of the importance of process parameter control in production.

Figure-2. The knowledge point interface in the cognition practice

4. Conclusion

Practice has proved that the teaching of virtual simulation project of chloroacetic acid production can make up for the deficiency of traditional unit operation experiment, and it was loved by students. The implementation provides a strong guarantee for students to comprehensively master the chemical engineering theoretical knowledge and effectively apply it to practice. At the same time, it increases students' understanding of the dynamic characteristics of the process parameter control system and the improvement of the operation and control ability. This plays an important role in cultivating students' technological process ability and engineering cognition. Although there are some deficiencies in virtual simulation technology, it is undeniable that it has become an important means to promote the integration of modern information technology into experimental teaching projects, expand the depth and breadth of experimental teaching content, and improve the level of experimental teaching.

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