Simulation training system of a circulating fluidized bed boiler

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Abstract—A circulating fluidized bed boiler as an important component of thermal power plant is used to make an investigation of simulation training software to solve a problem of study system independently lack for trainers and teaching software shortage for training directors. Authorware, a human-computer interaction tool, provides specific solving scheme to develop this software. The software development investigation shows that the simulation training system can demonstrate the equipments and system clearly and can strengthen fundamental knowledge easily for trainers and training director. Moreover, the material, energy conversion and transfer process of thermal power plant not only can be understood deeply by self-learners, but also it can be narrated conveniently by lectures.

Keywords: Engineering education; Simulation training system; Circulating fluidized bed boiler; Authorware; Power generation

I. INTRODUCTION

Boiler is indispensable combustion equipment in the process of an industrial production, which can provide us steam heat sources with higher temperature and higher pressure. Based on their working principle, many types of these boilers can be found in different industrial sections [1-5]. However, a circulating fluidized bed boiler as an important coal-fired boilers have become high energy steam generators of a lot of thermal power plants because of their advantages such as high burning efficiency, coal adaptability, high desulfurization efficiency, a small amount of nitrogen oxide emissions and ash reuse. With a development of science and technology, supercritical circulating fluidized bed boilers with 300 MW or more have been investigated widely because they have less than 6 percent coal consumption compared to coal consumption of subcritical boiler [6-8]. At present, supercritical circulating fluidized bed with a larger scale had been applied to industrialized process and good economic and social benefits also had been obtained simultaneously [9-11]. However, it is difficult to master the equipment system, the material transfer and energy conversion since equipment systems of a circulating fluidized bed boiler and physical and chemical process in them are very complex. Therefore, it is essential to study the process and system in order to solve this problem and to form a circulating fluidized bed simulation training system. Moreover, Authorware as an effective framework design tool can show the system equipment and illustrate the logical relation of transfer process and basic knowledge training by using human-computer interaction function [12-15]. However, programs written still have adjustment space and running effects lack background of engineering practice. Thus, aim of this work is to adjust the construction of program and to improve visual effect by adding actual industrial images based on references. Besides, form an exercises database for the software user. Finally, a circulating fluidized bed boiler simulation system will be established to achieve related basic knowledge of the circulating fluidized bed boiler equipment and system operation rapidly.

II. CIRCULATING FLUIDIZED BED BOILER SYSTEM

A. Fundamental Principle of the Technical Process

1) Combustion mechanism

Circulating fluidized bed boiler combustion belongs to fluidization combustion, a semi-suspension combustion, which is a kind of combustion between the suspension combustion of the pulverized coal furnace and the combustion of the chain grate. When the boiler is running, the bed materials which are composed of the ash in coal, the limestone, and limestone desulfurization reaction product are changed to the fluidized state under the effect of primary air across air distributing plate. Coal particle, bed material and limestone are entrained by flue gas in the furnace and move upward. During the movement of solid material and flue gas the large particles will fall along the wall of the furnace and form the inner circulation of the material. At the same time, the smaller solid particles are entrained into the cyclone by the flue gas. The majority of the particles are separated in the separator. Among them a

part of the material is directly returned to the furnace through the return valve, and the other part is returned to the furnace after heat transfer is done by the external heat exchanger, which forms the outer loop of the material. Under the running of the inner cycle of the furnace and the outer loop of the furnace, fuels reciprocating cycle combustion are implemented continuously. In the combustion process, the dense phase zone can ignite coal smoothly while dilute phase region can achieve the fuel combustion, exhaustion and heat transfer between gas-solid media in furnace and the evaporation heating surface to ensure the boiler output and furnace temperature control. The main reactions are expressed by equations (2-1), (2-2), (2-3) and (2-4):

$$C + O_2 = CO_2 \quad (2\text{-}1)$$

$$2C + O_2 = 2CO \quad (2\text{-}2)$$

$$S + O_2 = SO_2 \quad (2\text{-}3)$$

$$2R\text{-}N + O_2 = 2NO + R\text{-} \quad (2\text{-}4)$$

Where R-N and R- are an organic compound and a functional group, respectively.

2) Principle of pollutant reduction

(i)Sulfur oxides

Since working temperature of the circulating fluidized bed boiler is generally between 830℃ and 900℃, the limestone, calcium carbonate, can be reacted sufficiently and be decomposed to become calcium oxide at the temperature range. After that calcium oxide with oxygen of primary air and the sulfur dioxide produced by coal combustion are reacted to generate calcium sulfate, which is discharged in a solid form and complete desulfurization aim. Generally desulfurization efficiency of the process is more than 90 percent. The main reactions are given by equations (2-5) and (2-6):

$$CaCO_3 = CaO + CO_2 \quad (2\text{-}5)$$

$$CaO + SO_2 + 1/2O_2 = CaSO_4 \quad (2\text{-}6)$$

(ii)Nitrogen oxides

Because of lower combustion temperature of the furnace nitrogen oxides generated in a circulating fluidized bed boiler is mainly fuel type and a small amount thermal type. Grading air supply is used simultaneously to provide air in a circulating fluidized bed boiler. A primary air is fed from the air distributor while a secondary air is fed from the dense phase zone of by thermolysis. Secondly, these middle products are separated out from the coal to become volatile N. Lastly, volatile N is burned to be nitrogen oxides. The reaction mechanism is written by equation (2-7).

$$R\text{-}N \rightarrow HCN + NH_3 + CN + R\text{-} \rightarrow$$

$$NO + NO_2 + N_2O + R\text{-} \quad (2\text{-}7)$$

Where R-N and R- are an organic compound and a functional group, respectively.

(iii)Ash and slag

Due to the higher combustion efficiency of circulating fluidized bed boiler, residual fuel coal is very low, amount of fly ash and slag is less than 5 percent compared to the same level of pulverized coal furnace.

3) Principle of steam formation

Firstly, boiler feed water passes through economizer and enter steam drum. Secondly, water comes into water cooled wall across the descending pipe and absorbs heat from flue gas. Thirdly, gas-water mixture enters steam drum across rising pipe and does gas-liquid separation. Lastly, water will go to next cycle after separation while saturated steam will form superheated steam after it is heated by superheater. The superheated steam will be used to drive a steam turbine, which can drive generator to generate electricity.

B. Technological Process and System

The technological processes comprise mainly coal combustion, flue gas flow and water-steam conversion. Schematic diagram of the processes and system are shown in Fig.1. Fundamental processes are described as follows:

1) Coal combustion

Coal particle comes from the coal grinder is fed into the furnace by the coal feeder. At the same time, the desulfurization agent-limestone particle from the feed hopper is fed into the furnace. Under the participation of the primary air coal particle and limestone particle are mixed and reacted. Among the particles the larger react in dense phase zone combustion and the smaller react in the dilute phase zone. Combustion heat release and sulfur dioxide removal are completed during the process. However, some particles with the flue gas fly out of the furnace, most of which are captured by cyclone separator and are returned to furnace.

2) Flue gas

A great deal of high temperature flue gas produced after coal combustion pass through heating plate of superheater, reheater, economizer, the air preheater, desulfurization unit and so on, and then enter dust wiper to make dust removal. Finally, clean flue gas is discharged to atmosphere from a chimney by an induced draft fan.

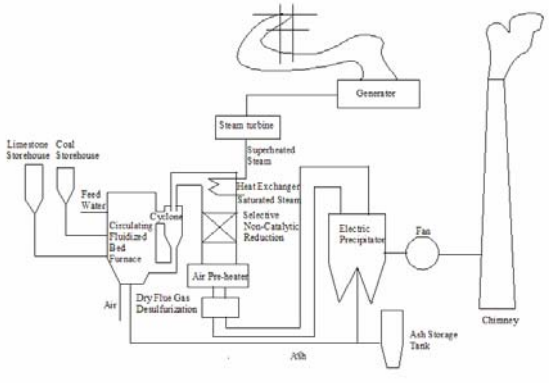

Figure 1. Schematic diagram of power generation system for a circulating fluidized bed boiler

3) Feed water

Boiler feed water firstly pass through economizer and enters steam drum. Then, boiler feed water enter water cooling wall across the descending pipe, which absorbs the heat generated from coal combustion in the furnace by radiation, convection and other ways. Afterwards steam-water mixture is formed and enters the drum again to

complete separation between steam and water. The water will participate in next water cycle across the descending pipe while saturated steam will flow into superheater to continue being heated and become superheated steam. Subsequently the superheated steam enters steam turbine and drives rotor to make work after separation, whose heat energy is converted to become mechanical energy. Finally, Steam turbine rotor drives generator rotor to generate electricity.

III. SIMULATION SYSTEM PRODUCTIONS

In order to make beginners of the power engineering understand operation process of a circulating fluidized bed boiler in a relatively short period and expand the computer software application in education and autonomic learning, modular design function of Authorware will be used to demonstrate clearly a circulating fluidized bed boiler of thermal power plant and to transfer fundamental knowledge under the static and dynamic form relevant to them. The design framework is expressed in Fig.2, which is mainly composed of recognition system, the system flow show and theory testing.

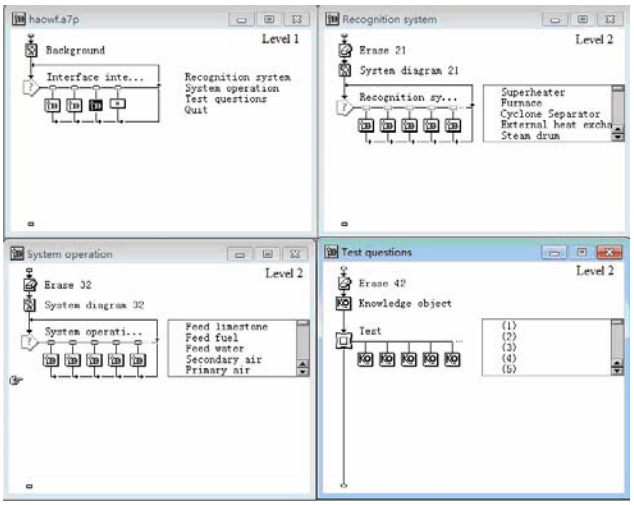

Figure 2 Software design framework

From Fig.2 we can comprehend that basic icons of Authorware such as display icon, interactive icon, frame icon, knowledge object icon and group icon, and the characteristics and integrated use of those icons can complete the framework design of the system.

A. *Static Demo*

First, drag a display icon to design interface and adjust the attributes and specific functions, create and display an initial interface as shown in Fig.3. Then, using graphics performance of Authorware, the system diagram as shown in Fig.4 can be drawn.

Second, make static cognition system. Analyze combustion system, steam-water system, equipment, process in thermal power plant and grasp the entire equipment name and their own roles then make "static cognition system". This part mainly use button interaction icon to complete this work. Drag a group icon and display icon into flow line, the name, equipment structure and function, and set a hot region. Regional scope is fixed on the device, and set a click. When click is run instruction of the equipment including text and picture will be displayed. The trainers can understand and learn the system by the static demonstration of the devices and equipments. The design levels of the recognition are shown in Fig.5. From the image of Fig.6, equipment and its functions can be stated distinctly. Not only it is apt to interpret equipment and its function for those trainers, but also it is convenient to comprehend the equipment and its physical picture in engineering practice.

Figure 3. Initial interface design software

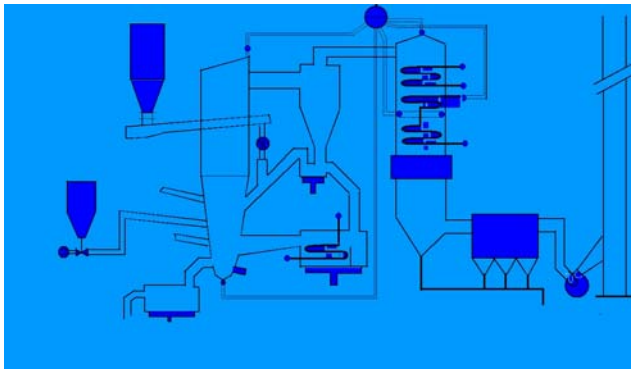

Figure 4 System diagram drawn by Authorware

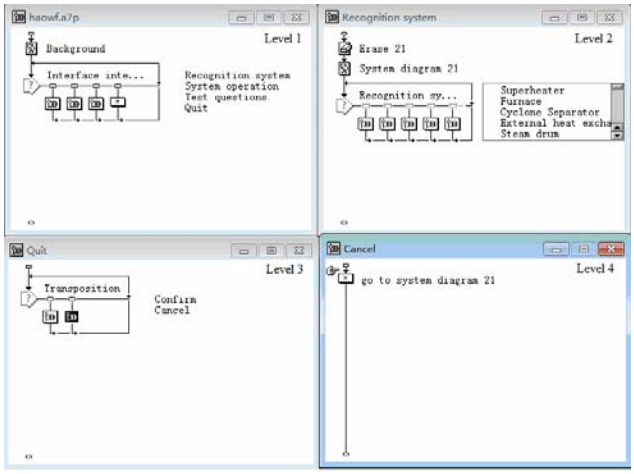

Figure 5 Schematic diagram of "Cognition system" structure

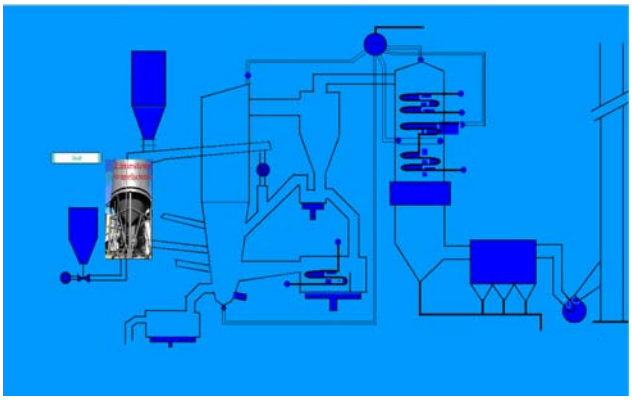

Figure 6 Static demo for the equipments

At the same time, operation and understanding of the process are also more intuitive. After a button is pressed, a material flow such as furnace gas current, water current, limestone feed current can be clearly indicated according to their own flow directions.

B. *Dynamic demo*

Prior to schematic diagram generation for a circulating fluidized bed boiler, combustion system, steam and water system and electrical system in thermal power plants should be fully understood. Moreover, material, energy conversion and transfer process in these systems should be mastered. A circulating fluidized bed boiler demonstration includes furnace gas system, limestone feed system, feed fuel system, slag discharge system, primary air system, secondary air system, smoke discharge system, feed water system and steam output system, whose demonstration interface is shown in Fig.7.

For the production of dynamic demonstration of the running system, indicators of furnace gas flow and water current as samples are used to reveal all kind of transfer processes in this paper. Red arrows shown in Fig.8 indicate a flow direction of the furnace gas, whose run process can show the flow direction of furnace gas when a power plant with a circulating fluidized bed boiler runs under a normal state. Navy blue coatings shown in Fig.9 reveal a trajectory of water current when the power plant runs. The process using Authorware production can be described as follows:

Background and buttons are deleted by using "erase" icon in level 2 and system diagram are inserted to flow line of level 2. Then use button interaction and "group" icons to form components of different substances flow. Besides, special effects of the coating or arrows for each schematic flow diagram are set. After the program runs different substance will appear in an order with different special effects, and ultimately a man feels that a substance is moving in equipments or pipelines. When button "quit" is pressed, operation system will be returned to an initial interface as shown in Fig. 2.

The production processes are shown in Fig.10 and Fig.11. The human-computer interaction is beneficial to understand and grasp mass transfer, heat transfer, momentum transfer and relevant to chemical reaction in a circulating fluidized bed boiler for trainers.

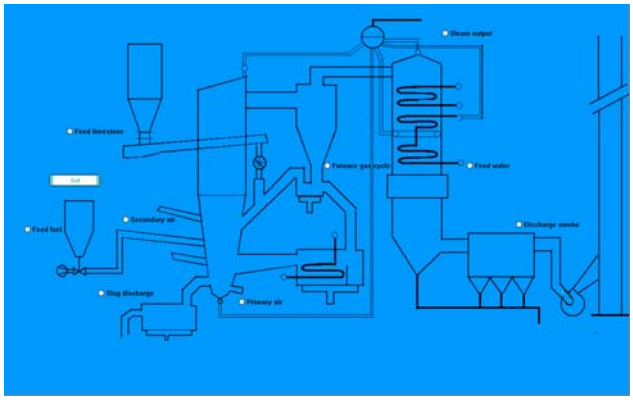

Figure 7 Operation interface of a circulating fluidized bed boiler

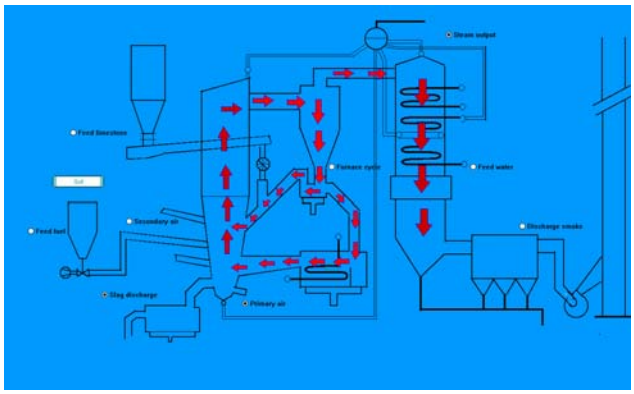

Figure 8 Flow chart for furnace gas

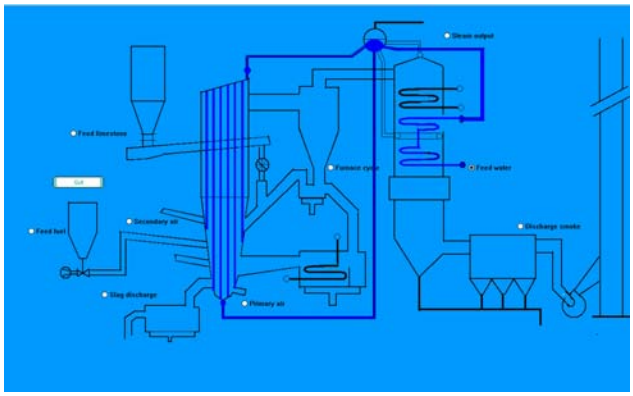

Figure 9 Water flow chart in pipeline

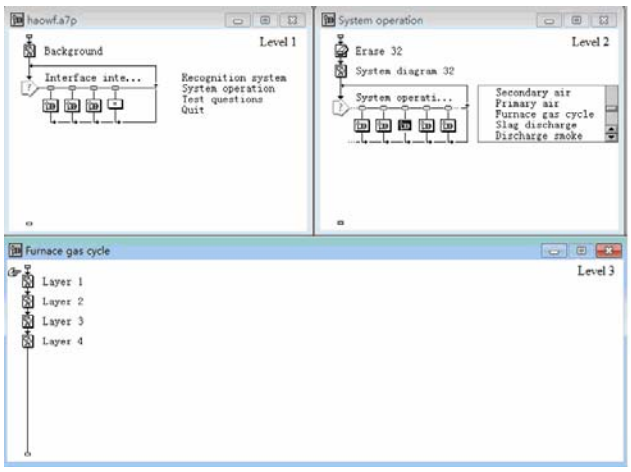

Figure 10 Production chart for flue gas flow

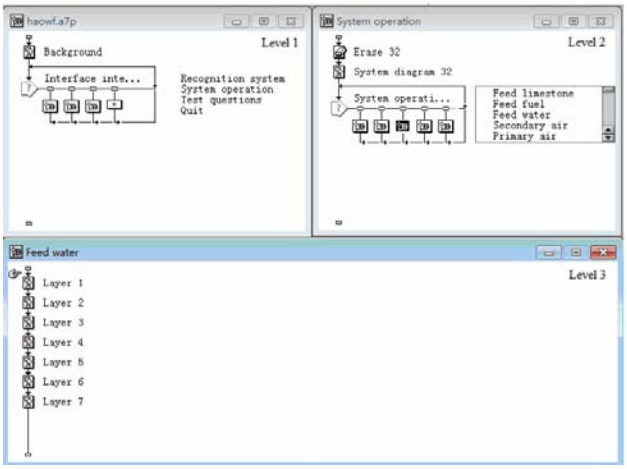

Figure 11 Production chart of water flow

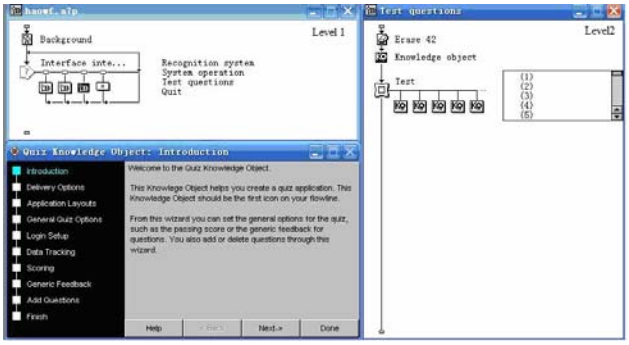

Figure 12 Production of test questions

Figure 13 Run schematic diagram of test questions

C. *Production of test questions*

In order to understand and grasp further the application of a circulating fluidized bed boiler, functions of navigation and knowledge object are applied to make test questions. During the production of the test questions, a navigation icon and some knowledge object icons are firstly dragged into test questions framework. Then selection response including page size, background, types and number are done according to page hint. 100 singel-choices, production procedures and effects example is shown in Fig. 12 and Fig. 13. Through the study of the production and the knowledge learning of a circulating fluidized bed boiler of thermal power plant, the trainers will have a deep understanding of the software itself and the fundamental knowledge of a circulating fluidized bed boiler.

D. *Formation of an executable file*

Training software with the static demonstration, the dynamic demonstration and the test question is packed to become an executable file of macromedia authorware 7 Runtime, which can be used to study independently and also be embedded to Powerpoint courseware to do training teaching of human computer interaction by lectures [16-18].

IV. CONCLUSIONS

After training software aforementioned is completed it can realize its functions of self-study or human computer teaching of lectures for a circulating fluidized bed boiler. From software production to software use, following conclusions can be drawn:

1. Process flowchart and some fundamental knowledge can be demonstrated clearly under the static state and dynamic state by the modular design function of Authorware. Test questions can help self-learners strengthen understanding and prolongation of basic knowledge for the trainers.

2. An executable file of Authorware can provide an independent self-study platform of operation and fundamental knowledge of a circulating fluidized bed boiler for the trainers.

3. Self-learners can not only have a more profound understanding of the material, energy conversion and transfer process of thermal power plant, but also they can master the method of process modular design through their own continuous learning.

4. Lectures can be easier to express the equipments and technical process and can be more convenient to narrate mass transfer, heat transfer, momentum transfer and chemical reaction for all kinds of substances when a courseware with an executable file is used to training teaching.

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