Autoclave operation simulation using iTthink software

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Abstract. This research article deals with an issue of temperature regulation in an autoclave. To solve this problem, it is proposed to use the simulation model of autoclave operation which can simulate the autoclave operation process with displaying the operation dynamics in a graphic form hour by hour depending on a number of input parameters as well as to simulate the mutual influence of control loops on each other.

1. Introduction
In order to avoid accidents, it is not recommended to analyze the impact of various factors in full, therefore, these studies are carried out in a simulation environment.

The authors' task was to develop an autoclave simulation model with the help of which - depending on a number of input parameters - to simulate the autoclave operation with the display of the operation dynamics in a graphic form hour by hour, as well as to simulate the mutual influence of control loops on each other.

During development of the model, available materials on manufacture of slag blocks in an autoclave produced from ash and slag materials from thermal power plants (Kumertau CHP plant) were used. The mutual influence of control loop in the autoclave was also taken into account.

The model was created in iTThink software simulation package.

2. Conceptual model of an autoclave for the production of slag blocks
The analysis of the results obtained during the experimental studies of slag blocks production from ash-and-slag materials of thermal power plants (including Kumertau CHP plant) using brown coal as a fuel shows that existing process equipment and layout do not allow to obtain finished products of the required quality. This is being hindered by the following main reasons: a wide range of fluctuations in the content of iron oxides in ash and slag materials (3 ÷ 27; in existing autoclaves saturated steam is supplied through a single pipe which does not allow to uniformly heat the entire volume of the autoclave and as a result the amount of rejects in the composition of finished slag blocks increases; in the existing process procedures for the production of slag blocks the acceptable rise and fall times of pressure and temperature in the autoclave are constant average statistical parameters that do not take into account the chemical composition of raw material which varies from batch to batch.

To reduce the amount of rejects in the composition of slag blocks subjected to heat and moisture treatment in the autoclave, it is proposed to feed the steam into the autoclave simultaneously by several pipes.
Figure 1 shows the dependence of amount of rejects (Brp) and thermal energy consumption (Q) on points (n) of steam supply to the autoclave. It follows from the figure that the reduction in amount of rejects (Brp) in the finished product after the heat-moisture treatment of slag blocks in the autoclave practically stops at n> 6, and energy consumption - at n> 5.

The design of the autoclave is shown in figure 2. It is a cylindrical body 1, the ends of which after the autoclave is loaded with slag blocks are sealed with covers 2.

![Figure 1. Amount of rejects (Re) and energy consumption (Q) as a function of steam supply points (n).](image)

Steam is supplied to the autoclave through pipe 7 and a valve with manual actuator F1, as well as through an adjustable valve F2. To the adjustable valves F5 ÷ F7, steam is supplied through valve F3, and to the adjustable valves F8 ÷ F10 - through valve F4. Steam is supplied to the upper and lower parts of the autoclave respectively via valves (F5 ÷ F7) and (F8 ÷ F10). The pressure in the autoclave is controlled by pressure gauges 8, and the temperature at six points is measured by sensors (T5 - T10). Steam from the autoclave is discharged through the adjustable valve F11 and the pipe 9.

![Figure 2. Design of the autoclave for the production of slag blocks from ash-and-slag wastes.](image)

4. Simulation of slag blocks production process in an autoclave in ithink environment

Visualization of object domain in iThink is done using classic cognitive maps. Models in iThink are represented by two hierarchical levels: the model level and the code level.

The model uses a type of structural blocks which is depicted as a figure consisting of a path and a valve, called a flow. Flow is a process that proceeds continuously in time which can be assessed in
physical or monetary units correlated with any time interval (rubles per month, liters per hour, etc.) [1]. In this model, two flows are used: "pipeline" and "exit".

5. Description of autoclave model
When creating the “Autoclave” model, a graphic function “Temperature vs. Time Graph” (figure 4) was assigned. In the iThink system it is specified by converters that use graphic functions being sketches of the relationship between specified input and output parameters [1].

The “Temperature vs. Time Graph” converter sets and adjusts the temperature for 12 hours (figure 4).

From the converter “Temperature vs. Time Graph” the steam is supplied through pipelines controlled by valves F5, F6, F7 and F8, F9, F10 to the converter “Heating” as shown in figure 3. This converter is designed to set the temperature so that it does not exceed the maximum value, which is equal to 190° C. Figure 5 shows the configuration of this converter.
In the "Equation" tab all made settings are automatically displayed on the program code level. You can also set the units of measurement, comments on parameters and formulas for simulation (figure 6).

After the launch of the process, according to the simulation results, the following statistics were obtained, presented in figure 7.

Figure 5. Setting the “Heating” converter.

Figure 6. “Equation” tab.

Figure 7. Table of autoclave control parameters.
6. Analysis of the resulting model

The temperature in the autoclave has a significant effect on the production of slag blocks which should not exceed a maximum value of 190° C.

Let us consider 5 different modes of autoclave operation:

- steam supply through all valves;
- steam supply through valves F5, F8;
- steam supply through valves F5, F6, F7;
- steam supply through valves F6, F9;
- steam supply through valves F5 и F10.

Let us consider the 1st mode of autoclave operation. In this case, steam is supplied through valves F5, F6, F7, F8, F9 and F10. In this mode, the heating of the autoclave inner space occurs evenly. The readings of all temperature sensors T5, T6, T7, T8, T9 and T10 fluctuates around 190° C. This is a reference mode of autoclave operation.

Let us consider the 2nd mode of autoclave operation when steam is supplied by pipelines through valves F5 and F8; valves F6, F7, F9 and F10 are closed. In the simulation, the temperature sensors T6 and T9 showed a temperature of 182° C, and the sensors T7 and T10 showed a temperature of 179° C. After 2 hours and 30 minutes, the temperature in the entire space of the autoclave became equal to 190° C.

Let us consider the 3rd mode of autoclave operation. In this mode, steam is supplied by pipelines through valves F5, F6 and F7; valves F8, F9 and F10 are closed. In the simulation, the temperature sensors T8, T9 and T10 showed a temperature of 188° C. After 1 hour, the temperature in the whole space of the autoclave became equal to 190° C.

Let us consider the 4th mode of autoclave operation. In this mode, steam is supplied by two pipelines through the valves F6 and F9; valves F5, F7, F8 and F10 are closed. In the simulation, the temperature sensors T5 and T8 showed a temperature of 182° C, and the sensors T7 and T10 showed 184° C. After 1 hour and 30 minutes the temperature in the whole space of the autoclave became equal to 190° C.

Let us consider the 5th mode of autoclave operation. In this mode, steam is supplied by two pipelines through the valves F5 and F10; valves F6, F7, F8 and F9 are closed. In the simulation, the temperature sensors T6 and T8 showed a temperature of 182° C, and the sensors T7 and T9 showed 183° C. After 2 hours, the temperature in the whole space of the autoclave became equal to 190° C.

Having analyzed all the operating modes of the autoclave, it was found that the 1st operating mode of the autoclave is the most efficient since steam is supplied through all the valves and the heating of the autoclave is more uniform and faster. The 2nd mode of operation is the worst since in this case the steam is supplied to the left side, the autoclave heats up rather slowly and unevenly, there are large temperature deviations: in the left part of the autoclave the sensors show a temperature of 190° C and in the right part 179° C.

7. Conclusion

The operation of the autoclave depends on many factors that can adversely affect the production of slag blocks, especially at a certain production rate.

From the analysis of the obtained model, it was revealed that, when steam is supplied evenly to the entire space of the autoclave, heating occurs more evenly and faster - this allows us to reduce the amount of rejects in the slag blocks.

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