DEVELOPMENT OF THE ADAPTIVE FUZZY CONTROL SYSTEM FOR A PARALLEL-FLOW DRYING DRUM

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Abstract. The process of removing liquid from the surface or inner layers of materials is widely used by various enterprises. To implement such a process, such a method of dehydration as drying is most often used. In drying technology, drum dryers are the most common type. Controlling a drum dryer causes problems such as low efficiency (0.4-0.6) and high operating costs. To eliminate these problems, it is proposed to develop a system of adaptive fuzzy control of a continuous-flow drum dryer in order to increase the efficiency of control of technological processes of drying sand by using intelligent technologies. The method for this article is adaptive control using fuzzy logic control, which has the ability to control the parameters of the dryer depending on changes in the parameters of the control object or external disturbances acting on the control object. Adaptive fuzzy controllers are created on the basis of the proposed method. A model of the control object has been developed taking into account the links between the parameters of the technological regime. The processing of the research results was carried out using the MatLab software. The practical significance of the article lies in the fact that the results can be used in enterprises where parallel-flow drying drums are used to obtain a product of the highest quality, as well as to reduce the cost of purchasing raw materials.

1 Introduction

The main purpose of the parallel-flow drying drum is to obtain a finished product with a moisture content of 0.4 – 0.5 %. To maintain the stability of the technological process, it is necessary to control it, taking into account the mutual influence of temperatures in the furnace, in the mixing chamber and in the drum itself [2, 12, 13, 14]. In cases where temperature control in the furnace does not allow maintaining optimal humidity, at low humidity, the temperature in the mixing chamber should be adjusted by increasing the supply of secondary air, and in a situation where the humidity is high, the number of revolutions in the drying drum should be reduced.

To control the parameters of a parallel-flow drying drum, a method will be used that makes it possible to transfer control to the appropriate controller, depending on the temperature value of the parameters or external influences. The proposed control system belongs to the class of adaptive control systems.

2 Description of the technological process and technological scheme of the production facility

In various sectors of the national economy, the processes of removing liquid (solvents) from the surface or from the inner layers of various materials are widespread. Among the existing methods of material dehydration (drying, squeezing, centrifugation, filtration, suction, absorption by chemical reagents, etc.), heat drying takes a special place, in which moisture is removed from the material mainly by evaporation.

Drying is a set of thermal and mass transfer processes at the surface (external task) and inside (internal task) of a wet material, contributing to its dehydration. Dehydration of materials, including drying, is intended to improve their quality and durability. There are the following types of dryers design: drying cabinet, chamber dryer, tunnel dryer, shaft dryer, belt dryer, drum dryer, rotary (contact) drum dryer, pneumatic dryer, fluidized bed dryer, vibration dryer [1, 3].

In our case, the object of control is dryer with a whirling drum (drum dryer), which is widely used in industry for drying materials of various aggregates and structure. [4].

For drum drying, flue gases obtained in the furnace as a result of fuel combustion are used as a heat carrier. The furnaces of drying installations are designed to create such an amount of combustion products that, by giving up the heat contained in it to the material to be dried, would be sufficient to heat the material to a predetermined temperature, evaporate the water contained in it and absorb the evaporated moisture [5].

Fuel (oil) and air enter the furnace F-1, where the combustion process takes place. Further, the flue gases are fed through the mixing chamber MC-1 to the drying

Table 1. Monitored parameters and control actions.

Controlled parameters (input variables):					
Parameter	Parameters in English	Simplified notation	Designation on the technological scheme	Range	Unit of measurement
Furnace temperature	Furnace temperature	TT	TE 5-a	700 – 900	°C
Mixing chamber temperature	Chamber temperature	TCK	TE 6-a	500 – 600	°C
Dryer temperature	Dryer temperature	TCБ	TE 7-a	200 – 300	°C
Sand moisture	Humidity	M	ME 11-a	0,3 – 0,6	%
Fuel consumption	Fuel consumption	FT	FE 1-a	20 – 120	m³/hr
Primary air flow	Air consumption1	FB1	FE 2-a	700 – 800	m³/hr
Concentration CO	Concentration CO	A	AE 4-a	10 – 150	mg/m3
Secondary air flow	Air consumption2	FB2	FE 3-a	200 – 300	m³/hr
Control actions (output parameters):					
Fuel valve opening degree	–	VT	1-b	0 – 100	%
Primary air valve opening degree	–	VB1	2-b	0 – 100	%
Secondary air valve opening degree	–	VB2	3-b	0 – 100	%
Frequency converter to control the drying drum rotation motor	–	FDD	PC-1	20-80	Hz
Turning on FC2	–	C1	–	–	–
Turning on FC3	–	C2	–	–	–
Turning on FC4	–	C3	–	–	–

drum DD-1. The wet material (sand) enters the hopper H-1 and through the dispenser D-1 is poured into the drying drum DD-1, in which the material is captured by helical blades, on which it is dried, and then moves along the drum, which has an angle of inclination to the horizontal up to 6°. Axial displacement of the drum is prevented by thrust rollers.

After drying drum sand is supplied to hopper B-2 and finished dried material is supplied through dispenser D-2.

Typically, in drum dryers, the material and the drying agent move in co-current flow, thereby preventing overdrying and entrainment of the material by flue gases in the direction opposite to its movement. To reduce entrainment during co-flow, the gas velocity in the drum is maintained at no more than 2-3 m/s. The gases come from the furnace F-1, adjacent to the drum from the material inlet side and equipped with a mixing chamber MC-1 for cooling the gases to the required temperature with outside air. After the drying drum, the sand is fed into the hopper H-2 and the finished dried material is fed through the dispenser D-2.

In the furnace F-1, the fuel is warmed up due to the heat received directly from both the incandescent lower layer of the burning fuel and from the hot flue gases passing through the fresh fuel layer; the fuel, warming up, dries up, that is, moisture evaporates from it. Then the release of volatile combustible substances begins, which ignite and burn, usually above the layer of burning fuel. A non-volatile residue remains in the layer, consisting of coke (carbon) and ash. The coke burns in the lower layer of the burning fuel, and the ash partially falls into the ash pan, from where it is removed, but it partially melts, turning into slag, which is removed from the grate during partial or complete cleaning of the furnace. A hot, burning layer of fuel oil, as well as its small particles in the furnace and volatile substances, burning in the furnace, give off heat to the heating surfaces of the solid fuel boiler. To prevent this, it is necessary to carry out pottering-down (stirring in the furnace of burning fuel). Pieces of fuel are freed from ash when pottering-down, they are again exposed to oxygen in the air and combustion improves. The product of fuel combustion in the furnace is flue gases [6]. Further, the flue gases entering the mixing chamber MC-1 are cooled due to the supply of secondary air.

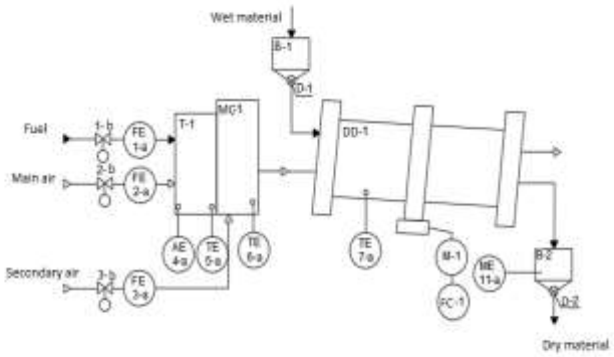

Fig. 1. Simplified process flow diagram of a parallel-flow drying drum.

Figure 1 shows a simplified process flow diagram of a parallel-flow drying drum.

For normal operation of the furnace, it is necessary to control the temperature in it (TE 5-a), which depends on the consumption of fuel entering the furnace (FE 1-a) and the flow of primary air (FE 2-a), regulated by valves 1-b, 2-b, respectively. The CO concentration in the furnace should also be monitored (AE 4-a). For further operation of the unit, the temperature in the mixing chamber (TE 6-a) should be controlled, which depends on the secondary air flow (FE 3-a), regulated by the valve 3-b. The temperature in the drying drum (TE 7-a) is also subject to control, the number of revolutions in the drum dryer is regulated by means of the frequency converter FC-1. At the exit from the parallel-flow drying drum, we get the final dry material with an acceptable moisture content (ME 11-a).

3 Determination of controlled parameters and control actions

Regulation of fuel and air consumption is necessary to maintain the optimum temperature in the furnace for complete combustion of fuel and to prevent an increase in CO concentration.

The amount of air supplied to the firebox must not be excessive.

Excessive combustion air supply lowers the flue gas temperature and increases the heat loss of the furnace. In addition, with an excessive amount of air supplied to the furnace, the torch cools too much and CO and soot begin to form. Also, insufficient air will cause incomplete combustion and the torch will cool too much and CO and soot will start to form. Therefore, in order to ensure complete combustion of the fuel and high combustion efficiency, the amount of air supplied to the furnace must be very precisely adjusted. [7].

In cases where temperature control in the furnace does not allow changing the humidity to the optimum, at low humidity, the temperature in the mixing chamber should be adjusted by increasing the air supplied to the mixing chamber, and in a situation where the humidity is high, the number of revolutions in the drying drum should be reduced.

4 Creation of fuzzy controllers for adaptive control

For adaptive control of the parallel-flow drying drum process, it is necessary to create 4 fuzzy controllers [9]:

FC1 – fuzzy controller for adapting the control system;

FC2 – the fuzzy controller is used in situations where it is necessary to regulate the amount of fuel and primary air supplied to the furnace to maintain optimal sand moisture;

FC3 – fuzzy controller is used in situations where it is necessary to regulate the amount of secondary air supplied to the mixing chamber to maintain optimal sand moisture;

FC4 – fuzzy controller is used in situations where it is necessary to adjust the rotational speed of the drying drum.

Taking into account the tendency of sand moisture state change, adaptive control is carried out with the help of FC2 – FC4.

Figure 3 shows a block diagram of fuzzy adaptive control. The adaptive control system includes fuzzy controllers FC1 – FC4. The fuzzy controller FC1 is designed to adapt the control system (Figure 2). FC1 receives the current values of sand moisture M and temperature in the T_T furnace. Taking into account the tendency of changing the state of sand moisture, adaptive control is carried out using the controllers FC2 – FC4. In case of deviation from the preset ranges, the controllers FC2 – FC4 are switched on by supplying control signals C1 – C3 to the corresponding controller. The fuzzy controller FC2 is designed to regulate the amount of fuel and primary air supplied to the furnace to maintain the optimum moisture content of the sand (Figure 4). The input parameters for FC2 are the fuel consumption F_T, the primary air flow F_{B1}, the CO A concentration, the degree of opening of the fuel supply valve V_T, the degree of opening of the primary air supply valve V_{B1}, as well as the values of sand moisture M and temperature in the furnace T_T. The output parameters of FC2 are the degrees of opening of the primary air supply valve V_{B1} and the fuel supply valve V_T. Fuzzy controller FC3 is designed to regulate the amount of secondary air supplied to the mixing chamber to maintain optimal sand moisture content (Figure 5). The input parameters for FC3 are the secondary air flow F_{B2}, the temperature in the mixing chamber T_{MC}, the degree of opening of the secondary air supply valve V_{B2}, as well as the values of sand moisture M and temperature in the furnace T_T. The output parameter FC3 is the secondary air supply valve V_{B2}. Fuzzy controller FC4 is designed to regulate the rotational speed of the drying drum (Figure 6). The input parameters for FC4 are: temperature in the drying drum T_{DD}, the frequency of rotation of the drying drum F_{DD}, as well as the values of sand moisture M and temperature in the furnace T_T. The output parameter FC4 is the frequency converter FC_{DD}.

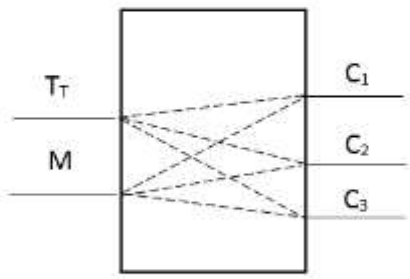

Fig. 2. Conceptual model FC1.

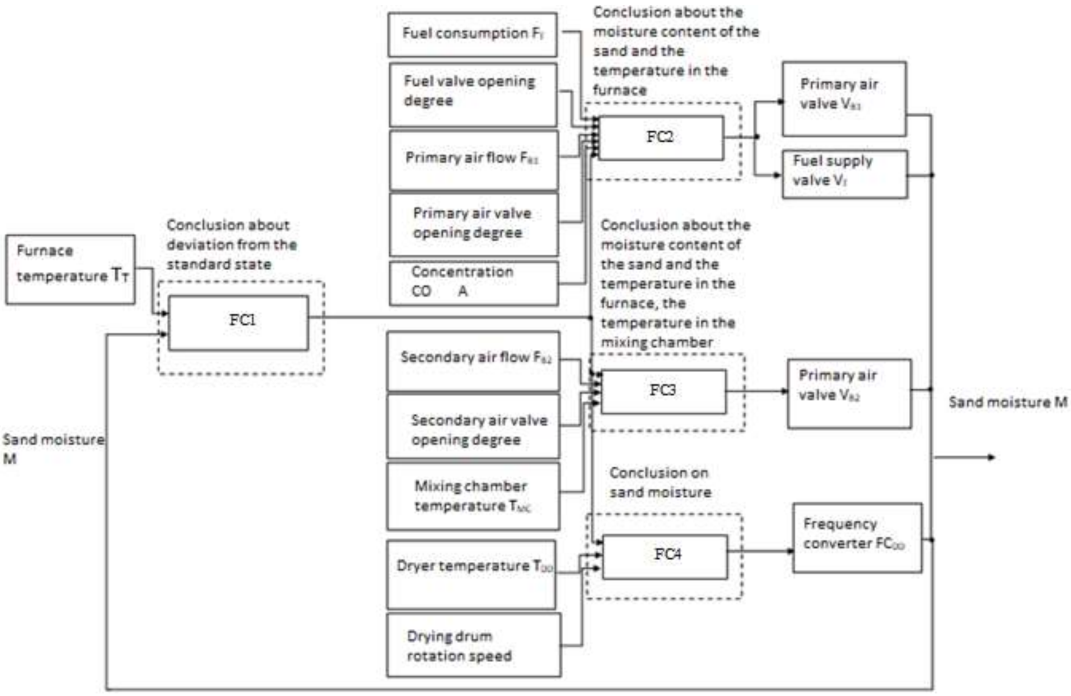

Fig. 3. Block diagram of fuzzy adaptive control.

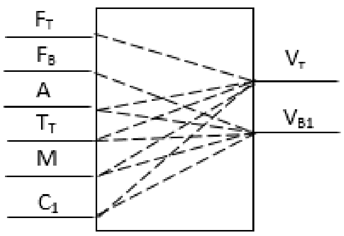

Fig. 4. Conceptual model FC2.

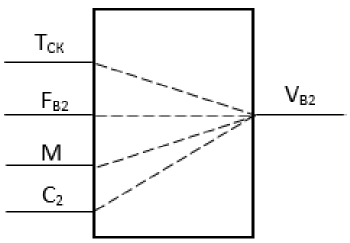

Fig. 5. Conceptual model FC3.

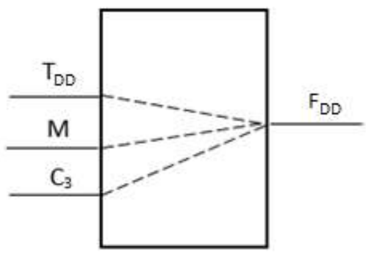

Fig. 6. Conceptual model FC4.

For the implementation of controllers FC1 – FC4, rules have been set that describe the functioning of the drum dryer control system. Below is one rule for each controller. The rest of the rules are set similarly [10].

Rule for FC1 adaptation of the control system:

If the temperature in the T_T furnace is high and the humidity M is high, then FC4 is switched on.

Rule for FC2 adaptation of the control system:

If the temperature in the T_T furnace is average and the humidity M is high and the fuel consumption F_T is average and the primary air consumption F_{B1} is average and the concentration A is low, then the fuel valve V_T is open and the primary air valve V_{B1} is half-closed.

Rule for FC3 adaptation of the control system:

If the temperature in the T_T furnace is low and the humidity M is low and the temperature in the mixing chamber T_{DD} is average and the secondary air flow F_{B2} is low, then the secondary air valve V_{B2} is half-open.

Rule for FC4 adaptation of the control system:

If the temperature in the T_T furnace is high and the humidity M is high and the temperature in the T_{DD}

drying drum is average, then the power of the P_{DD} drying drum is low.

5 Creation of fuzzy controllers in Fuzzy Logic Toolbox

Let's simulate fuzzy controllers FC1 – FC4 in the Matlab environment using the Fuzzy Logic Toolbox extension package based on fuzzy logic (Figure 7) [8].

One of the following parameter control knobs FC2 – FC4 is activated depending on the output of the FC1 controller. FC2 turns on when it is necessary to regulate the amount of fuel and primary air supplied to the furnace to maintain optimal sand moisture content, FC3 – in situations where it is necessary to adjust the amount of secondary air supplied to the mixing chamber to maintain optimal sand moisture content, FC4 – in situations where it is necessary to adjust the frequency rotation of the drying drum.

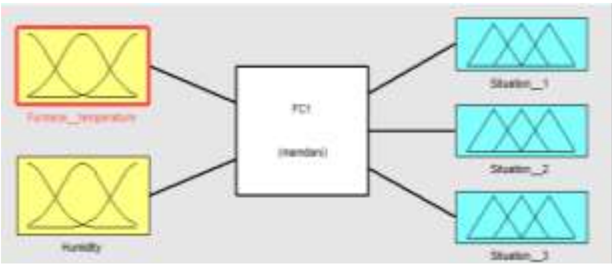

Fig. 7. Situation analysis controller FC1.

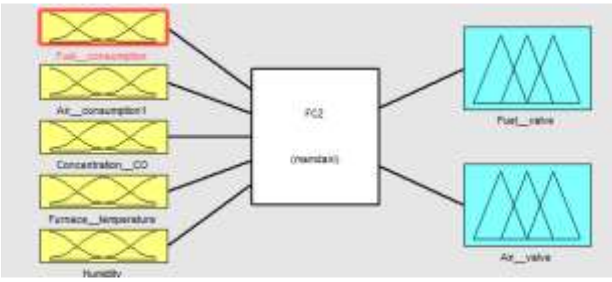

Fig. 8. Situation analysis controller FC2.

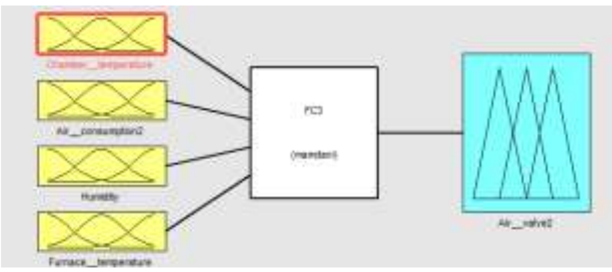

Fig. 9. Situation analysis controller FC3.

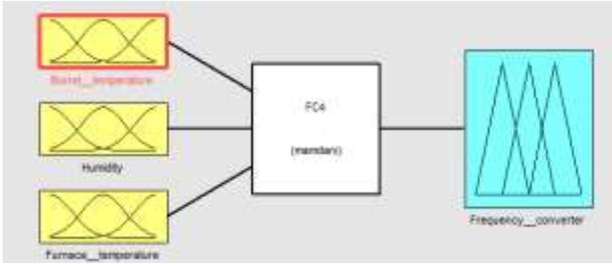

Fig. 10. Situation analysis controller FC4.

6 Simulation of the drying process in the Simulink environment

To build the circuit, the environment for dynamic interdisciplinary modeling of complex technical systems Simulink was used.

Figure 11 shows a basic parameter control model for sand moisture control developed in the Simulink system. The used parameters are described in Table 1.

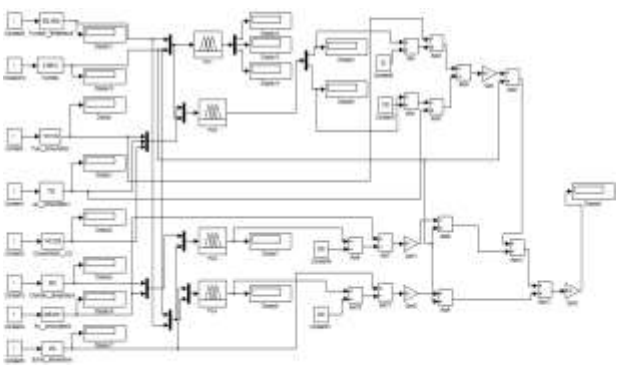

Fig. 11. Model of control of the main parameters of the drum dryer.

6.1 Description of fuzzy controllers FC1 in the model

Figure 12 shows the initial values for fuel consumption, air consumption, CO concentration and sand temperature.

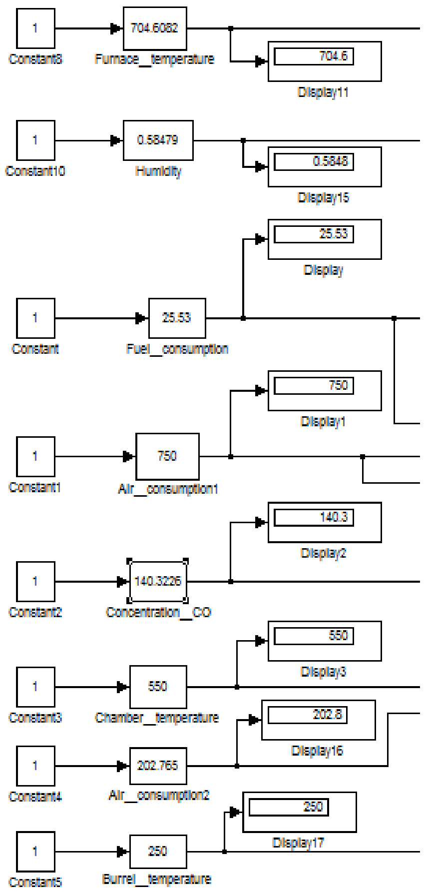

Fig. 12. Setting the initial parameters.

Figure 13 shows the fuzzy situation analysis controller FC1. Using the initial values, the FC1 controller makes a conclusion about possible situations. Figure 12 shows that the moisture content of the sand is outside the permissible norm of values. In this situation, the fuzzy controller FC2 turns on.

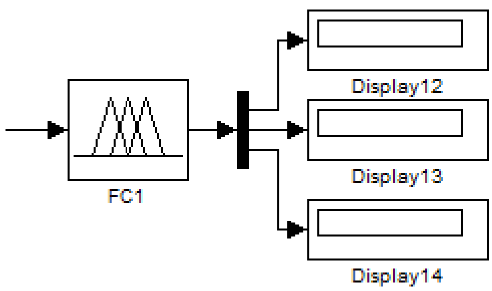

Fig. 13. Fuzzy situation analysis controller FC1.

6.2 Modelling the FC2 controller

To simulate the FC2 controller, we use the rule:

If the temperature in the TT furnace is low and the humidity M is high and the fuel consumption FT is low and the primary air consumption FB1 is medium and the concentration A is high, then the fuel valve VT is half-open and the primary air valve VB1 is half-closed.

Let's make the input variables to this rule. To do this, move the slider in the Slider Gain blocks to positions close to the maximum or minimum values.

Output of sand humidity readings in hopper B-2 on Display 6 is shown in Figure 14.

The outputting sand moisture readings in the B-2 bunker on Display 6 is shown in Figure 14.

The dependence of the sand moisture on the degree of opening of the fuel and primary air supply valves is determined by the following relationship:

$$M = M_{OUT} + (0.001 \times ((-F_T + 20 + V_T) + (F_{B1} - 700 - V_{B1}))\%. \quad (1)$$

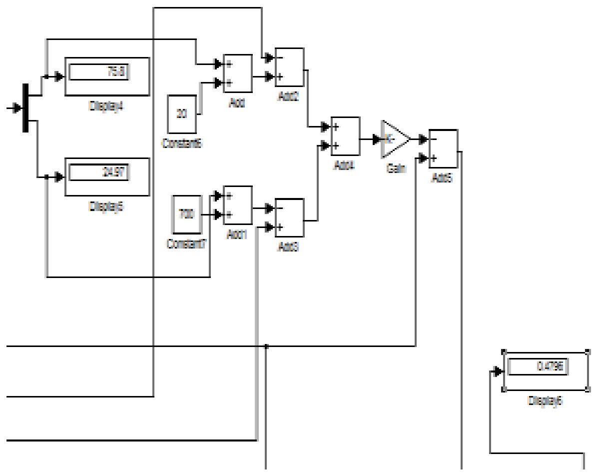

Fig. 14. Displaying the readings of the moisture content of the sand in the B-2 bunker on Display 6.

Table 2. Results of adaptation of parameters in FC2.

Before adaptation	After adaptation
Humidity, %	
0,586	0,48

After analyzing Table 2, we can conclude that the decrease in the sand moisture index was due to the use of the method of controlling the fuel supply and air supply valves, which takes into account their mutual influence.

6.3 Modeling the FC3 controller

To simulate FC3, we will use the rule:

If the temperature in the TT furnace is low and the humidity M is low and the temperature in the mixing chamber TMC is average and the secondary air flow rate FB2 is low, then the secondary air valve VB2 is half-open.

Displays of the readings of the moisture content of the sand in the B-2 bunker on Display 6 are shown in Figure 15.

The dependence of sand moisture on the degree of opening of the secondary air supply valve is determined by the following relationship:

$$M = M_{OUT} + (0.001 \times (F_{B2} - 200 - V_{B2}))\% \quad (2)$$

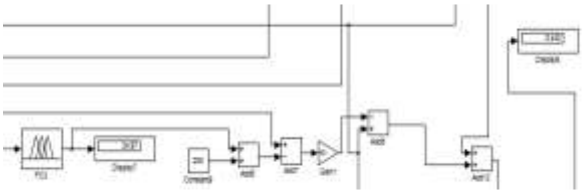

Fig. 15. Displaying the readings of the moisture content of the sand in the bunker B-2 on Display 6.

Table 3. Results of adaptation of parameters in FC3.

Before adaptation	After adaptation
Humidity, %	
0,586	0,443

After analyzing Table 3, we can conclude that there was a decrease in the sand moisture index by partially closing the secondary air supply valve.

6.4 Modeling the FC4 controller

To simulate FC4, let's use the rule:

If the temperature in the TT furnace is high and the humidity M is high and the temperature in the TDD drying drum is average, then the rotation power of the PDD drying drum is low.

Displays of the readings of the moisture content of the sand in the B-2 bunker on Display 6 are shown in Figure 16.

The temperature dependence on the rotational power of the drying drum is determined by the following dependence:

$$M = M_{OUT} + (0.005 \times (-T_{dd} + 200 + P_{dd}))\%. \quad (3)$$

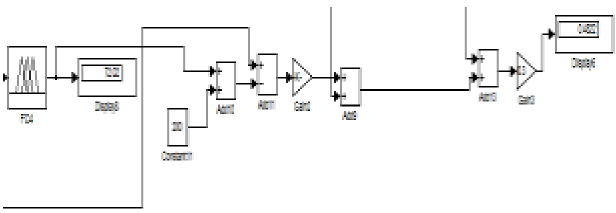

Fig. 16. Output of sand moisture in the B-2 bunker on Display 6.

Table 4. Results of adaptation of parameters in FC4.

Before adaptation	After adaptation
Humidity, %	
0,586	0,4822

After analyzing table 4, we can conclude that the decrease in the moisture content of the sand was due to an increase in the rotation power of the drying drum. If you increase the frequency of rotation of the drum, then the sand will quickly come out of the drying drum due to the fact that the drum is at an angle of 6-8 degrees, this reduces the cost of energy, labor and time [4].

7 Conclusion

The article deals with the synthesis of fuzzy adaptive control of a parallel-flow drying drum. Controlled parameters and control actions were defined, which take into account the mutual influence of the parameters. Conceptual models of fuzzy controllers FC1 - FC4 are obtained. Controller FC1, depending on the temperature in the furnace and the moisture content of the sand, concludes which of the fuzzy controllers FC2 - FC4 will be activated to maintain the optimum moisture content of the sand. Controller FC2 is designed to control the supply of fuel and primary air to the furnace, taking into account their mutual influence. Controller FC3 is used to control the supply of secondary air to the mixing chamber. Controller FC4 is used to control the rotational speed of the drying drum. On the basis of the developed conceptual models of controllers, they were simulated in the Fuzzy Logic Toolbox package. After that, the drying process control system was simulated in the Simulink environment.

The use of the developed adaptive control system allows you to get a product of the highest quality, increase productivity, reduce the time of the process, increase the accuracy and stability of the operations performed.

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