UDC 669.162.231.92

Control model of the heating hot blast stove regenerative chamber based on fuzzy knowledge with training set

Alexander Simkin

Ph.D., Associate Professor
Department of Automation and Computer Technologies,
State Higher Educational Institution "Pryazovskyi State Technical University"
Mariupol, Ukraine

Elena Kobysh

Graduate student
Department of Automation and Computer Technologies,
State Higher Educational Institution "Pryazovskyi State Technical University"
Mariupol, Ukraine

Abstract
In the analysis of the experimental data of hot blast stove fuzzy knowledge base was formed. In accordance with the fuzzy knowledge base fuzzy control model of heating regenerative chamber of the hot blast stove was realized. Adjusting of developed fuzzy model by the training set was fulfilled. The article presents a comparative analysis of the results of model operation with different forms of defining of membership functions of input and output parameters.
Key words: HOT BLAST STOVE, BLAST FURNACE GAS, HIGH-CALORIE ADDITIVE, FUZZY KNOWLEDGE BASE, MEMBERSHIP FUNCTION

Statement of problem

Heating of regenerative chamber of the blast stove is fulfilled with the help of blast furnace gas or mixed gas. The need to use mixed gas appears at an insufficiently high caloric blast furnace gas. In this case, it becomes appropriate to add high-calorie supplements (natural, coke oven gas or fuel oil) to the low-calorie blast furnace gas.

During the heating process of regenerative chamber of the blast stove using mixed gas, the change total heat of combustion is possible by changing the flow rate of one of the components: the blast furnace gas or high calorie supplements. The most commercially acceptable is a gradual decrease in the consumption of expensive high-calorie supplements during heating of regenerative chamber. Traditionally, the control system receives the values of only two main parameters that characterize the state of the regenerative chamber temperature: the temperature in the dome space and flue gas temperature at the outlet of the regenerative chamber, so the decision to change the high-calorie supplement consumption during heating of regenerative chamber must be taken on the basis of these temperatures. In determining the depending on the desired flow rate of high-calorie supplements on the temperatures of the dome and the bottom of regenerative chamber of particular interest is the consideration of the above parameters in terms of fuzzy sets. This approach allows to reveal the structure of the knowledge base on the heating process of regenerative chamber and control of heating on the basis of the systematic framework of logical rules.

The purpose of the article is to develop a fuzzy model of heating of regenerative chamber of the blast stove with the implementation of this model for setting training set and analysis of simulation results for various forms of membership functions of input and output parameters.

Analysis of research and publications

Temperature control of the dome by changing the flow of high-calorie fuel is considered in [1]. At the same time heating the regenerative chamber going in a maximum possible flow of air, and the ratio of "fuel-air" is adjusted by changing the flow of blast furnace gas. It is noted that this approach does not consider a temperature of the bottom regenerative chamber as the main parameter that characterizes warmup of the blast stove fixture along the height.

Total fuel consumption, based on the calculation of the heat balance of the gas and blast periods is defined in [2]. The work [3] is devoted to research of law of variation of caloric content of blended fuel depending on the current state of the regenerative chamber temperature. Description of the process of creation of fuzzy knowledge base of Mamdani type, on the basis of which, development and the subsequent adjustment of fuzzy model according to the distinct one or fuzzy training sample takes place, is presented in the works [4, 5].

Representations of the materials and results

As the high-calorie additive to the blast furnace gas, the natural gas was selected. The heat of combustion of the gas mixture is determined by the equation [1]:

$$Q_{mix}(\tau)=\frac{Q_{b.g.}(\tau)\cdot F_{b.g.}(\tau)+Q_{n.g.}(\tau)\cdot F_{n.g.}(\tau)}{F_{b.g.}(\tau)+F_{n.g.}(\tau)}, \quad (1)$$

where $Q_{b.g.}(\tau)$ – combustion heat of the blast furnace gas, kcal/m^3, $Q_{n.g.}(\tau)$ – combustion heat of the natural gas, kcal/m^3, $F_{b.g.}(\tau)$ – consumption of the blast furnace gas, m^3/s, $F_{n.g.}(\tau)$ – consumption of the natural gas, m^3/s.

From the equation (1) it follows that the consumption of natural gas necessary for maintaining the desired caloric mixture is calculated as:

$$F_{n.g.}(\tau)=F_{mix}(\tau)\cdot\frac{Q_{mix}(\tau)-Q_{b.g.}(\tau)}{Q_{n.g.}(\tau)-Q_{b.g.}(\tau)} \quad (2)$$

As input values of fuzzy model the temperature of the dome and the temperature of the bottom of regenerative chamber were adopted. The output value is represented by the control action, which provided for a change in caloric fuel mixture by reducing the consumption of high-calorie supplements - natural gas. Fuzzy sets were generated for the input and output parameters.

Fuzzy knowledge base is based on the evaluation of the dependence of dome temperature and fixture bottom of hot-blast stove on the calorific value of gas mixture. In result of experimental data analysis, obtained during work of the block of hot blast stoves at the BF№2 of Ilyich Iron and Steel Works, there was formed fuzzy knowledge base based on the rules of «if – then», in accordance with which a logical decision is formed. Weighting factor which value is within the range [0; 1] and characterizes subjective measure of confidence in the truth of the expert rules, corresponds to each rule. While developing fuzzy knowledge base Mamdani type is selected, where the values of the consequent rules also as antecedents are set by fuzzy terms [5].

Linguistic terms for input parameters (temperatures of the dome and bottom) are indicated: T_{d1},T_{b1} - «refrigerated», T_{d2},T_{b2} - « initial stage of heating», T_{d3},T_{b3} - «warming-up along the height», T_{d4},T_{b4} - « final stage of heating». Linguistic terms for output parameter (control action) are indicated: Y_1 - «high», Y_2 - «above the average», Y_3 - «below average», Y_4 - «low».

In the development of fuzzy models there were investigated two options for specifying the membership functions of the input and output values of fuzzy sets. Gaussian membership function is defined by the equation:

$$) = e^{\frac{-(x-b)^2}{2c^2}} , \qquad (3)$$

where $\bar{b}, \bar{c}$ - are vectors of parameters, presented by coordinate of the maximum and concentration factor of the membership function.

The bell-shaped membership function is calculated as follows:

$$\mu(x) = \frac{1}{1+(\frac{x-b}{c})^2} \qquad (4)$$

The tuning is made to adjust the behavior of fuzzy models according to training set, which is represented by an array of 150 pairs of experimental data "input-output", obtained from the block of the blast stoves at the BF№2 of Ilyich Iron and Steel Works. In the process of tuning there is a search of the model parameters, in which the difference between the simulation result and the experimental data is minimal. So, the tuning of fuzzy model is to solve the following optimization problem [4]:

$$R = \sqrt{\frac{1}{M}\sum_{i=1}^{M}(y_i - f(\bar{x}_i, \bar{w}, \bar{c}, \bar{b}))^2} \rightarrow \min , \qquad (5)$$

where M - is the number of pairs of experimental data $(\bar{x}_i, y_i)$, $\bar{w}$ - vector of weighting factors in the fuzzy rules.

To solve this problem there was chosen the conjugate gradient method with Polak-Ribiere formula. Error identification while using Gaussian membership functions before tuning is 6.78%, after tuning it is 4.24%, with bell-shaped membership functions - 10.04% and 4.98% respectively. Results of fuzzy model tuning are shown in Fig.1-3 and Table 1.

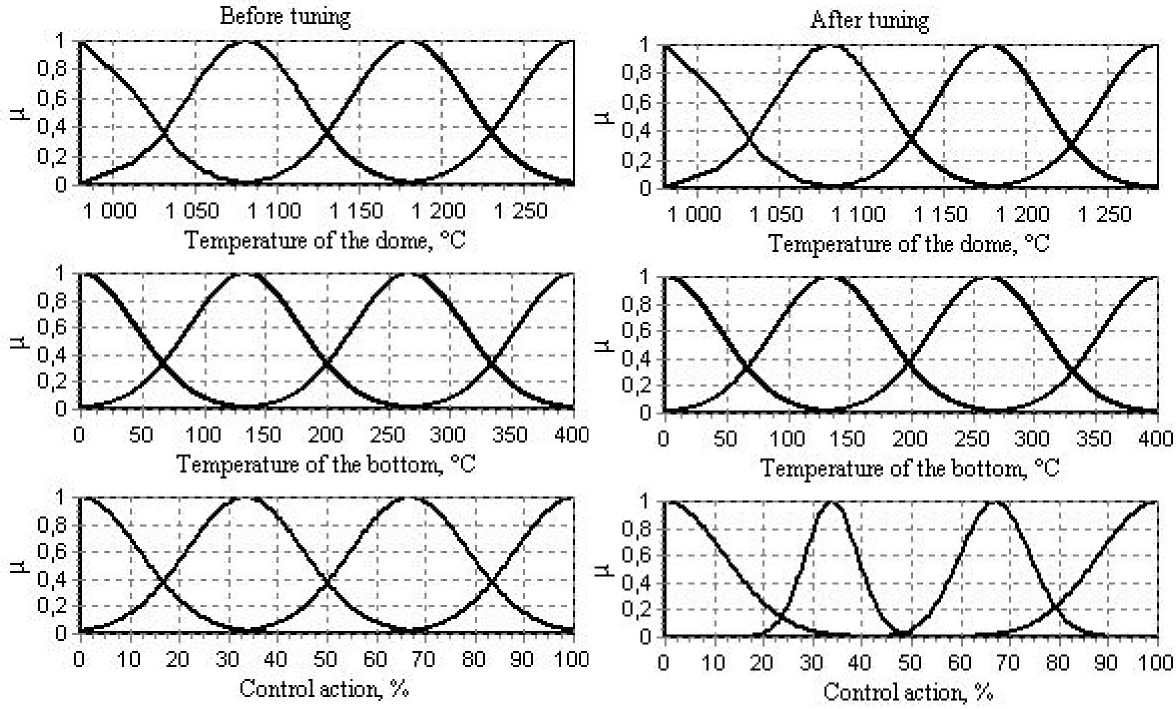

Figure 1. Gaussian membership function

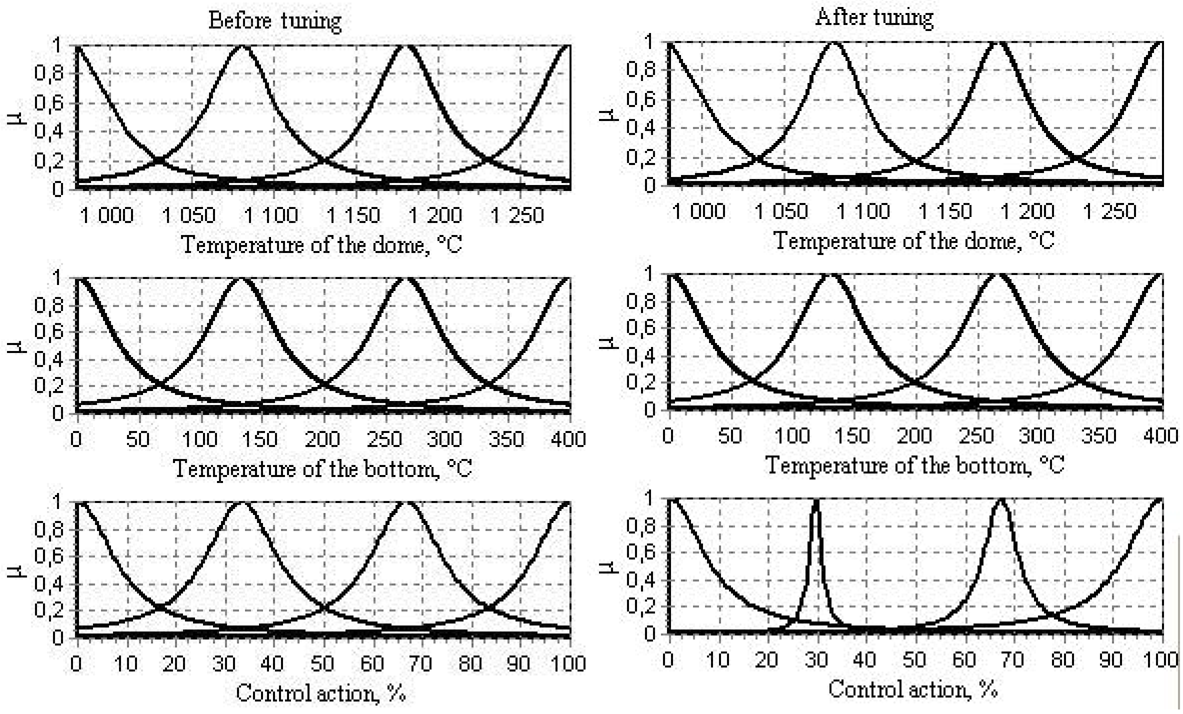

Figure 2. Bell-shaped membership function

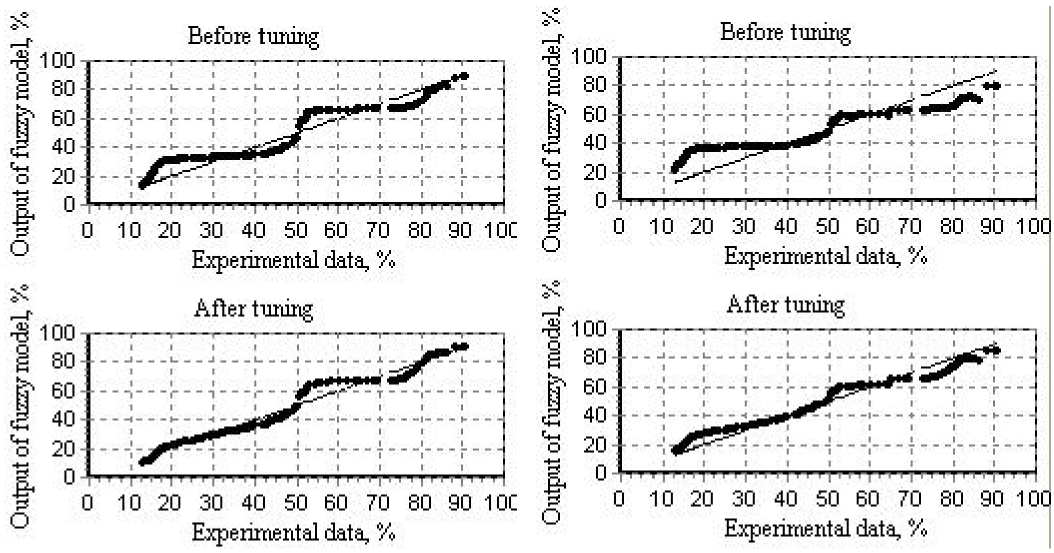

Figure 3. Results of testing of fuzzy model with: a – Gaussian membership function, b - bell-shaped membership function

Table 1. Fuzzy knowledge base

Temperature of dome	T_{d1}	T_{d1}	T_{d2}	T_{d2}	T_{d2}	T_{d3}	T_{d3}	T_{d3}	T_{d3}	T_{d4}	T_{d4}	T_{d4}	T_{d4}
Temperature of bottom	T_{b1}	T_{b2}	T_{b1}	T_{b2}	T_{b3}	T_{b1}	T_{b2}	T_{b3}	T_{b4}	T_{b1}	T_{b2}	T_{b3}	T_{b4}
Control action	Y_1	Y_1	Y_1	Y_2	Y_2	Y_2	Y_2	Y_3	Y_3	Y_3	Y_3	Y_4	Y_4
W before tuning	1	1	1	1	1	1	1	1	1	1	1	1	1

W after tuning	gaus-sian	1	1	1	0.8	1	1	1	1	0.6	1	1	0.9	1
	bell-shaped	1	1	1	0.9	0.8	1	0.8	0.8	0.9	1	1	0.9	1

The work of the block of the hot blast stoves at the BF№2 of Ilyich Iron and Steel Works are going under the temperature of the hot blast air within 960-1000°C. The temperature of the dome during the heating does not exceed 1280 °C (technological limit). The end of the heating period is considered the moment, when temperature of the regenerative chamber bottom is reached 400 °C (technological limit). According to the calculation of fuel combustion [6], produced in the analysis of experimental data, it was found that the heat of combustion of the fuel mixture during heating varies within 800-1000 kcal/m^3. Participation of developed fuzzy model as part of a top-level of ACS of the preparation of blast air for heating control of hot blast stove using fuel-rich high-calorie supplement is suggested. There is data transmission from the fuzzy control model into previously developed subprogram for calculating of fuel combustion and getting by fuzzy model of the required data from the subprogram of mathematical modeling of heating of regenerative chamber, also developed earlier [6]. General scheme of organization of the computer complex is shown in Fig.4. The results of testing of fuzzy control model by fixture heating on the base of mentioned computer model of hot-blast stove operation are shown in Fig.5 and Table 2.

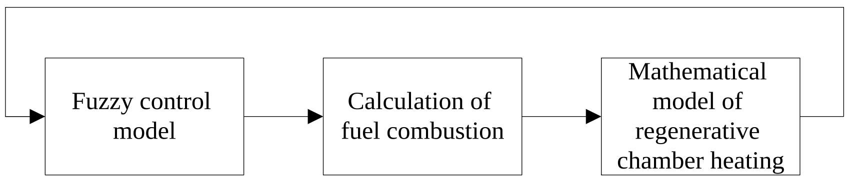

Figure 4. General scheme of computer complex of simulation of hot blast stove

As it is seen from the Fig.5 during fuzzy model work with application of bell-shaped membership function on the graph of flow variation of natural gas there are more vast areas of non-convexity. So, the Gaussian membership function is more acceptable for fuzzy modeling of processes typical for heating of the regenerative chamber.

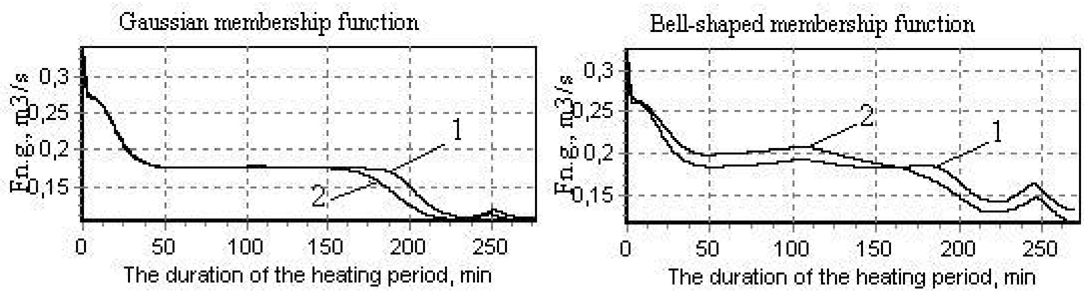

Figure 5. Consumption of natural gas: 1- before tuning, 2 - after tuning

On the base of results of computer simulation shown in Table 2, it can be concluded that tuning of the fuzzy model based on the bell-shaped membership function did not significantly influence on the change of total consumption of natural gas. Using Gaussian membership function after tuning of fuzzy model there is a reduction in the total consumption of natural gas by 40 m^3.

Table 2. Results of fuzzy modeling

Parameter \ Membership function	Gaussian		Bell-shaped	
	Before tuning	After tuning	Before tuning	After tuning
Consumption of natural gas, m^3	2741.6	2701.2	2970.8	2983.3
The amount of heat transferred to the blast air by the period, GJ	576.7	576.5	570.3	572.9
The duration of the heating period, min	276	277	271	271
The duration of the blast air period, min	119	119	118	118

Conclusion

1. On the basis of the fuzzy knowledge base there developed Mamdani fuzzy control model of the heating of regenerative chamber of blast stove with reducing the consumption of natural gas. Application of fuzzy knowledge base and tuning of the model enables to fulfill structured approach to the control heating of hot blast stove. One of the main advantages of fuzzy knowledge base is the ability to use minimum information about the modeled object. Fuzzy knowledge base is formed on information about the input and output parameters. This is the most acceptable, taking into account such features of heating of regenerative chamber, as permanent change of heat of combustion of blast furnace gas, and thus the total calories of supplied fuel mixture.

2. In the process of tuning of fuzzy model for the training set there was solved the problem of minimizing the mean square discrepancy between the output of the model and the experimental data. After tuning of fuzzy model for Gaussian and bell-shaped membership functions, identification error does not exceed 5%.

3. In a joint operation of the developed fuzzy models with subprogram for calculation of fuel combustion and a mathematical model of the regenerative chamber heating there was found that the use of Gaussian membership function with the same duration of the blast air heating period could reduce the total consumption of natural gas by 282 m^3 as compared with the work of fuzzy model with bell-shaped membership functions.

4. On the base of fuzzy knowledge base it is possible to solve problems that arise in the control systems of the heating of hot blast stove, as well as problems related to the identification of non-linear functions specific to the preparatory process of blast air. Fuzzy control model of heating of regenerative chamber refers to the top-level software of ACS of blast air preparation. Co-operation and data exchange between presented fuzzy model, subprogram for calculating of fuel combustion and the model for regenerative chamber heating are suggested.

References

1. Gres L.P. *Vysokoeffectivnyj nagrev domennogo dutya* [High-efficiency heating of blast-furnace blast]. Dnepropetrovsk, Porogi, 2008, 492 p.
2. Romanenko V.I., Marchenko A.I., Ponizovcev I.M. (2009). On the question of optimization of thermal control of blast furnace air heaters work. *Metallurgicheskaya i Gornorudnaya Promyshlennost.* No 3, p.p. 58-60.
3. Kobysh E.I., Simkin A.I., Kravchenko V.P. (2014). Heating control algorithm of hot-blast stove fixture with inner combustion chamber. *Stal,* No 1. p.p. 9-13.
4. Rotshtein A.P., Shtovba S.D. (2006). Intensification of nonlinear dependence by indistinct knowledge base with indistinct training sample. *Kibernetika i sistemnyj analis.* No 2, p.p. 17-24.
5. Shtovba S.D. (2007). Adjustment of fuzzy model conserning training sample with indistinct output. *Kibernetika i sistemnyj analis.* No 3, p.p. 26-32.
6. Kobysh E.I., Simkin A.I., Koifman A.A. (2012). Computer model of hot-blast stove working. *Reporter of Priazovskii state technical university, collection of scientific works.* Mariupol, Vol. 25, p.p. 239-245.