Genetic algorithm usage for optimization of saturator operation

Volodymyr Polupan, Victor Sidletskyi

National University of Food Technologies, Kyiv, Ukraine

Abstract

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Introduction. It is carried out the research of the optimal control adaptive system of the apparatus of II saturation. Qualitative indexes of the adaptive control system efficiency are defined.

Materials and methods. Adaptive control system of a sugar refinery apparatus of II saturation was studied. Simulation modeling based on classical and hybrid genetic algorithms is used to determine the optimal performance parameters.

Results and discussion. The simulation studies of the quality of functioning of the structural model of the adaptive system of optimal control using the classical genetic algorithm are carried out, as well as the research of the modified genetic algorithm with the addition in the classical algorithm the hybrid functions, namely *fmincon*, *fminsearch* *patternsearch* *fminunc*.

Adaptive system of optimal control has significantly lower integral quadratic criterion $I = 545$ comparing to the existing one, which integral quadratic criterion $I = 658$. Moreover, control time is also reduced. Adaptive control system requires $T = 109$ s, while existing control system requires $T = 212$ s. Usage of hybrid functions allowed to additionally reduce integral quadratic criterion to $I = 529\text{--}541$ and to speed up the system, required time $T = 98\text{--}105$ s. Also, a study of the *fmincon* method without the use of a genetic algorithm was carried out, this model showed a lower execution time $T = 88$ s, but the value of the integral quadratic criterion $I = 604$ was higher.

The best results in terms of integral quadratic criterion and time ($I = 529$, $T = 98$ s) were obtained for genetic algorithm combined with *fmincon* hybrid function.

Developed adaptive control system for saturator operation significantly outstands the existing one by all the main indexes. That is why it is highly recommended to replace control system on the sugar refinery with the studied adaptive one.

Conclusions. The novelty of the research results is the scientific substantiation of the feasibility of using classical genetic and hybrid genetic algorithms in the implementation of adaptive optimal control systems.

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Corresponding author:

Volodymyr Polupan
E-mail:
serunderw@gmail.com

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Introduction

Second saturation apparatus is an unsteady object from the point of view of control – with time flow its parameters unpredictable alter within wide range. Moreover, it works under uncertainty of environment parameters, load and raw material quality. Therefore, there is always a lack of prior information, mathematical models, which describe alterable properties of the objects and environment, do not exist.

Automatic regulators, which were adopted considering initial values of the object parameters, cannot provide sufficient control quality under such conditions. In the last several decades, different improvements for design of control systems were proposed [1–4]. However, the usage of genetic algorithm (GA) in control systems of sugar refinery saturators was not properly studied. Thus, arise a necessity to improve control algorithms and to provide adaptive control system [5, 6].

The objective of this paper is to study the saturator's adaptive control system, which is based on genetic algorithm.

Materials and methods

The second saturation apparatus is a control object, where filtered juice after the first saturation reacts with carbon dioxide. As a result of this reaction calcium salts sediment. The objective of the second saturation optimization is to maximize the sedimentation of calcium salts. Therefore, the amount of calcium ions in the filtered juice must be minimized [7].

The parametric scheme of a control object is shown in Figure 1.

The main material flow in the second saturator is the flow of first saturation filtered juice x_1 . Disturbance of z_2 group under normal work conditions has no significant influence on the uniformity of juice flow on the second saturation area.

The more significant is the disturbance of z_3 group. However, alteration of these characteristics takes considerable time. To maintain presets of quantitative indices of second saturation juice (p_1, p_2, p_3) it is necessary to perform control actions u_1, u_2, u_3, u_4 . If disturbance of a group z_1 or z_2 is dire, it is necessary to control juice inflow directly.

If the juice level in the collector before the evaporator is considerable or the group z_3 equipment has failed, then juice inflow is limited [8].

The juice pH decrements with the decrement of calcium ions concentration C in the second saturation juice (curve 1 in Figure 2). Hence, considering the pH measurability during the production process, this index is used as a state variable. Moreover, calcium ions concentration and juice pH as well as electrical conductivity X and juice pH (curve 2 in Figure 2) are interrelated with unsteady extreme dependence. The drift of these characteristics has the peculiarity that the minimum of both curves always corresponds to the same value of pH. Considering non-availability of calcium ions concentration sensors, a new criterion of control can be used – electrical conductivity of a saturated juice. Therefore, a control criterion of the second saturation process, considering iterative problem solving, is following:

$$I = \frac{1}{n} \sum_{i=0}^{n-1} (pH_{opt,i} - pH_i)^2 \rightarrow \min \quad (1)$$

where n – number of pH_{opt} determinations at regular intervals Δt during the saturation process $n = TIME/\Delta t$; $TIME$ – saturation process duration [9].

Figure 1. The parametric scheme of a second saturation apparatus:

z_1 – disturbance, caused by the material flow rates alteration of:

x_1 – first saturation filtered juice, m^3/h ;

x_2 – lime milk, m^3/h ;

x_3 – carbon dioxide, m^3/h ;

x_4 – sulphur dioxide, m^3/h ;

x_5 – filtration sediment, m^3/h ;

x_6 – juice to clear yellow sugar, m^3/h ;

x_7 – evaporated water, m^3/h ; in the second saturation apparatus;

y_1 – sulphited juice output rate, m^3/h ;

z_2 – disturbance, caused by the alteration of:

z_4 – carbon dioxide concentration in the saturation gas, %;

z_5 – lime milk density, g/cm^3 ;

z_6 – lime milk contamination, %;

z_3 – disturbance, caused by the alteration of characteristics of:

z_7 – pumps;

z_8 – heaters;

z_9 – filters;

z_{10} – second saturation apparatus;

z_{11} – equipment serviceability;

TC – technical constrains of n_1 – sulphited juice level in the collector, m ;

u – control action to maintain presets of flow rate of:

u_1 – first saturation filtered juice, m^3/h ;

u_2 – lime milk, m^3/h ;

u_3 – carbon dioxide, m^3/h ;

u_4 – sulphur dioxide, m^3/h ;

TI – technological indices:

p_1 – environment reaction, pH units;

p_2 – second saturation juice purity, %;

p_3 – environment reaction of sulphited juice, pH units.

A well-known regression model describes the dependence of the pH value on the consumption of saturation gas (F_{sg}), the temperature of the diffusion juice (T_{dj}), the density of limestone milk (C_{CO2}), the lime milk consumption (F_{CaO}), the density of dry matter (C_{dm}) [17]:

$$\begin{aligned} pH(F_{sg}, T_{dj}, C_{CO2}, F_{CaO}, C_{dm}) = & -15,01 - 54,123F_{sg} - 34,982T_{dj} + 0,982C_{CO2} + \\ & + 6,862C_{CP} + 71,936F_{CaO} - 3,973F_{sg}T_{dj} + 7,946F_{sg}C_{CO2} + 28,361F_{sg}C_{dm} - \\ & - 1,804F_{sg}F_{CaO} - 1,765T_{dj}C_{CO2} - 9,082T_{dj}C_{dm} + 4,095T_{dj}F_{CaO} + 9,635C_{dm}F_{CaO} - \\ & - 2,985T_{dj}^2 + 4,729F_{sg}^2 + 5,028C_{CO2}^2 - 8,027C_{dm}^2 + 8,941F_{CaO}^2 \end{aligned}$$

Figure 2

Figure 3. Sensitivity of second saturation qualitative index

Results and discussion

Optimal control system description

A system of optimal control was built to solve the problem, the structural scheme of which is shown in Figure 4. Control Computing Complex (CCC) of the system consists of mathematical model unit (MMU) and optimal control unit (OCU). The former receives information from sensors at regular intervals and defines current state of the saturation process, the latter calculates pH_{opt} and perform a dynamic optimization [10, 11]. Automatic regulator damps the disturbances, which influence the pH of the saturated juice. There are few assumptions considering adaptive system modelling. Firstly, disturbances (measurable and immeasurable) have influence only on the objective function pH extremum drift. Secondly, information collection, processing and output time is considered insignificant, comparing to inertial properties of the object, and thus is neglected.

Figure 4. Optimal control system

CCC solves problem of second saturation process control using genetic algorithm (Figure 5).

Genetic algorithm explanation

Genetic algorithm is an evolutionary algorithm of heuristic search, that is used to solve optimization problems by modelling of natural selection, crossover and mutation, which occur during life of living organisms [12]. GA are effectively used to solve multiple-criteria optimization problems. A certain amount of chromosomes determines an individual, which is evaluated with objective function (also known as fitness function). A certain amount of individuals determines population. During the “evolutionary process” genetic material is gathered and the algorithm quickly “moves” towards the vicinity of the optimal solution. The advantages of genetic algorithms include the reliability, the ability to work with discrete and continuous values, GA finds the solution to the problem, without considering all the possible solutions. Genetic algorithms are weakly sensitive to local extrema [12].

Figure 5. Genetic algorithm

Initial generation of a population consists of many problem solutions (also known as individuals), each with its own set of chromosomes, which is created randomly, usually. Then every problem solution is evaluated with objective function. Therefore, every set of chromosomes has its own fitness value (objective function value), which determines how good each solution to the problem is.

The second generation of a population is created from the selected problem solutions of the initial generation [13]. Usually better problem solutions (better in terms of the objective function) have higher probability to be selected to take part in creation of the second generation. Then the genetic operators, such as crossover and mutation, are applied to the selected problem solutions [14]. As a result, we have second generation. Every problem solution of this generation is also evaluated with objective function. Then this process repeats. Some of the problem solutions are selected to create the third generation, genetic operators are applied to them and so on.

These actions are iterative modelling of evolutionary process, which are repeated until the stop criterion is met. A stop criterion can be:

- global optimal or quasi-optimal solution;
- total amount of the generations created;
- total amount of evolution time.

Thus, one can distinguish the following stages of the genetic algorithm (Figure 5).

1. Objective function formulation.
 2. Initial generation creation and its objective function evaluation.
- Iterative part.
3. Problem solutions selection.
 4. Crossover.
 5. Mutation.
 6. Objective function evaluation
 7. Check if stop criterion is reached.

As one can see it is not necessary to create a perfect initial generation of a population. GA can quite quickly improve the population due to usage of crossover and mutation operators. Initial generation H consist of N problem solutions [15].

Crossover, mutation and selection. Genetic algorithm, usually, use two parent solutions to create one child solution [16]. Different GA have different ways to produce child solutions. The main requirement is that child solution must be able to inherit genes of each parent solution. To produce the next generation only the individuals of the current generation is used.

Control process simulation

The program works as follows:

- initial value pH_{in} is entered before the saturation process start (Figure 6);
- units $a1$ and $b1$ generate values (Figure 6);
- genetic algorithm is used to solve (1) and define optimum (Figure 6);
- during the time $T = 100$ s unit “Dinamic” calculates transition process considering pH_{in} and pH_{opt} . Results are shown in unit “Scope”. pH_{opt} is in pH_{opt} array.

Figure 6. Simulation model

To simplify the dynamic calculation additional unit “Dinamic1” is used. Its inputs are static value of pH_{in} and dynamic value of $(pH_{in} + pH_{opt})$. Its output forms transition process with duration of 100 s of system time.

Simulation results

Simulation was carried out according to the requirements of the technological process considering different production peculiarities. Values from the sensors were read at a given time. That is initial values. Every simulation was carried out for the existing control system and for the adaptive one. Also, besides classic GA a bunch of hybrid functions were used in addition to GA: *fminsearch*, *patternsearch*, *fminunc*, *fmincon*. Eq. (1) was used to assess control quality. Results are shown in the Table 1.

Table 1

Hybrid function	I		T, c	
	Existing control system	Adaptive control system	Existing control system	Adaptive control system
None	658	545	212	109
<i>fminsearch</i>	-	541	-	105
<i>patternsearch</i>	-	536	-	102
<i>fminunc</i>	-	537	-	102
<i>fmincon</i>	-	529	-	98
<i>fmincon</i> without GA	-	604	-	88

As on can see from the table 1, adaptive control system has significantly lower integral quadratic criterion $I = 545$ comparing to the existing one, which integral quadratic criterion $I = 658$. Moreover, control time is also reduced. Adaptive control system requires $T = 109$ s, while existing control system requires $T = 212$ s. Usage of hybrid functions allowed to additionally reduce integral quadratic criterion to $I = 529$ – 541 and to speed up the system, required time $T = 98$ – 105 s. The best results in terms of integral quadratic criterion and time ($I = 529$, $T = 98$ s) were obtained for genetic algorithm combined with *fmincon* hybrid function. If control system uses *fmincon* without GA to solve the problem, then it requires even less time $T = 88$ s, however it can find local optimum while losing a global one. Considering this flaw, an adaptive control system must use both GA and *fmincon* hybrid function.

Therefore, the research objective was met and developed adaptive control system for saturator operation significantly outstands the existing one by all the main indexes. That is why it is highly recommended to replace control system on the sugar refinery with the developed adaptive one.

Conclusions

Simulation results confirmed that developed adaptive control system for saturator operation is highly efficient. The best control criterion values of the second saturation process were achieved when classic genetic algorithm was combined with hybrid function *fmincon*.

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