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Editors
Roman Szewczyk
Industrial Research Institute Automation and Measurements PIAP
Warsaw
Poland

Małgorzata Kaliczyńska
Industrial Research Institute for Automation and Measurements PIAP
Warsaw
Poland

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Automation of Evaporation Plants Using Energy-Saving Technologies

Anatoliy Ladanyuk, Olena Shkolna(✉), and Vasil Kyshenko

National University of Food Technologies, Kiev, Ukraine
{ladanyuk,evlens}@ukr.net, kvdl948@gmail.com

Abstract. The article deals with methods and ways of energy saving automatic control of sugar factory evaporators based on modern control theory, including a number of approaches that can provide both basic tasks of finished-product output and saving of energy and material resources. A great importance of an evaporator plant is admitted not only in a technological complex, but also in a heating complex of a sugar factory as a supplier of secondary steam for other subsystems of technological complex, such as vacuum devices and various heaters, to ensure their proper functioning.

Keywords: Evaporator · Technological processes · Energy saving technologies · Energy saving control · Food production

1 Introduction

The problem of energy-saving control in the sphere of production is being paid much attention to in recent years. The methods, means and algorithms of the efficient control are applied to provide the solutions to the basic tasks of final product manufacturing with some special limitations related to energy and material resources use [1]. It takes place at automation of different technological objects (technological processes, units and complexes). The modern theory of control allows applying some approaches to the systems of complex objects. These approaches are directly used to determine high technical and economic indexes of functioning by means of using smart technologies [2], adaptive and robust-optimal control, diagnostic methods and prognostication, situational and precedential control, etc. [3, 4]. All these methods help to save either material, or energy resources at product cost decrease and provision of its quality.

The given article considers the modern methods of evaporator (E) control at sugar factory.

2 Formulation of the Problem and Investigation Methodology Selection

Considering the problem of evaporator (E) energy saving control, it is recommended to determine the main aspects of (E) functioning from the point of view of system analysis, its place in technological and heat power complexes, its impact on general

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technical and economic indexes of sugar factory work. This means (E) features and work indexes have to be estimated in complex way.

Technological and thermal technical features of evaporator functioning in regard to energy saving is presented in diverse by their completeness sources [5–11]. It is showed, that at the conditions of fuel and energy resource (FER) cost increase, their fraction in the processing cost of 1 t of sugar beets is 30–32% and even more and in sugar cost is up to 20% and more. Fuel consumption amounts nearly 6%. Its decrease causes the enterprise profitability increase correspondingly and is considered by heat reduction consumed by technological needs. It exceeds 80% of the overall FER balance cost and reduces heat losses (technological vapor from power plants). So, it makes approximately 32% beets mass (specific losses of heat energy 160 Mcal/t of beets). But the enterprises in Western Europe have the indexes 17–23% and 87–110 Mcal.

The evaporator at a sugar factory is the main consumer of technological vapor. It performs the technological function by thickening diffusive juice, thermal heating function by providing customers with the secondary vapor (vacuum apparatuses and heaters) and power plants with condensate.

It is necessary to take into account some complex interconnected factors while estimating the indexes of E functioning. For example, in order to reduce vapor losses, it is advisable to decrease the total amount of venting from E units. At the same time it is recommended to support the required syrup concentration by the correct venting distribution. It can result in evaporation of the necessary amount of water from juice otherwise; it can decrease the amount of diffusive juice (pumping). Possible compression of the secondary vapor is considered, as well as the decrease of diffusive juice pumping. It is achieved due to the introduction of deep pulp squeezing, redirecting the pulp pressing water to the diffusive process, beet chip and feed water quality increase, etc.

One more problem is the application of film apparatuses at the final units of evaporator which leads to the concentration of 70–72% for syrup and provides the continuous E functioning at optimal mode. It is achieved because of the qualitative juice purification, silt forming inhibitor application, etc. So, the modern automation system design is becoming of the highest priority and is considered further in the given article.

It is also important to mention that the decrease of diffusive juice pumping can cause, firstly, syrup thickening increase. Evaporator lacks juice and water has to be supplied into purified juice or E units. Secondly, evaporation multiplicity increase and venting shift to rear units lead to E efficiency exceed compared to the required one.

Some articles, for example [8], can show the cases of the Harrington function and pinch analysis method application in order to estimate heat energy systems at sugar factories. The Harrington function (desirability function) is applied to solve multi criterion tasks, for instance, to optimize multidimensional objects. It is used to find solution for energy saving tasks by selecting one of the variants for efficiency estimation. Pinch analysis methodology is focused on the minimization of chemical process energy losses by calculating thermal dynamically implemented target energy. It is an integration process (heat and heat power energy). As a result, it has been calculated, that 60–70 kg of returned vapor is taken to process 100 kg of sugar beets, the factories of Western Europe take 40 kg, but the application of film vapor apparatuses can reduce it up to 25 kg. The total implementation of technological and heat energy measures allows decrease of energy consumption to 20–45%. The effective modern automation systems will facilitate this as well.

Evaporators are considered as the components (of subsystem) of heat power complex. It is connected to other subsystems with numerous material and energy flows and the processes of operation information exchange. Any of these systems is characterized by specific modes and functioning indexes, optimality criteria and mathematical models. The terms of energy saving control for complex dynamic objects are presented in [12]. It highlights the necessity to use special the automatic and automated systems.

3 Methods of Energy Saving Control

In order to formalize the task of energy saving control the mathematical model of object is presented in form within the coordinates of state:

$$\begin{cases} \dot{X} = Ax + Bu + D_1 w \\ Y = Cx + D_2 w \end{cases} \tag{1}$$

where: $X(t) \in R^n$ – the coordinate state vector, $U(t) \in R^m$ – the vector of control actions; $Y(t) \in R^l$ – the vector of output variables, $W \in R^{m_1}$ – disturbances or task signals, A, B, C, D_1, D_2 – the matrixes, here matrix A has always $n \times n$, where n – the system order.

Optimality criteria:

$$I_1 = \int_{t_0}^{t_k} f_0(U(t))dt \tag{2}$$

or

$$I_2 = \int_{t_0}^{t_k} U^2(t)dt \tag{3}$$

to minimize energy consumption, or

$$I_3 = \int_{t_0}^{t_k} |U(t)|dt \tag{4}$$

to minimize fuel consumption.

Tasks (1)–(4) consider function $f_0(U(t))$ which determines the form of functionality, where t_0, t_k – the beginning and end of control time interval. The value intervals are set as the values for the state coordinates, output variables and control actions.

Evaporator functioning can be characterized by situational uncertainty which corresponds to the multiplicity of states of functioning H:

$$\dot{X} = f_n(X, U, t, \gamma_h), h \in H, \quad (5)$$

where γ_h – the massif of model parameters in state h.

Special attention has to be paid to the formulation and the methods of multi criteria task solutions [14].

The task of optimal control system development has been of current interest up to now. This system is able to provide synthesis of energy saving control actions in real time at changes of object functioning state. The principle of maximum is used to determine the optimal programs by applying optimality criteria (2), (3), (4). But the object range here is restricted when it is necessary to count the programs again at changes of initial data within the time interval of control, for instance, for multistage processes. The method of dynamic development is applied to such objects, although, some difficulties can appear because of large dimension of the task. The problems of control limit consideration, term fulfillment and weight coefficient selection can also take place when applying the methods of analytical design of optimal regulators (ADOR). The mentioned above methods are not able to provide the obtaining of effective control actions at situational control. One of the methods to solve the mentioned problems is the method of synthesized variables [10] application. It allows the fast determining of form and parameters of optimal control directly for the determined massif of initial data, i.e. object model parameters, control limitations, etc.

Taking into account the importance of evaporator in heat energy complex at sugar factory, it is necessary to select the methods of energy saving control. The connections of different subsystems, their stage, possibilities to plan the losses of energy sources within a single integrated structure of automation system has to be considered as well. The methods of proactive and energy saving control [12–15] can be used for this purpose. The generalized assessment of technological and heat power complexes is the criterion of energy efficiency. This criterion considers either production volumes or resources consumption needed for this production. The prediction models can also be used. These models are based on the statistical data related to: output-resource consumption. However, such models do not possess high precision and are not able to consider constant changes of production situations. Here, the principle of proactive control is the most efficient when the technical and economic indexes of production are used before the resources are over. The simple methods of operative estimation of technical and economic indexes are, as a rule, incorrect and statistically shifted. For example, the direct operative estimation of the specific indicator of product energy consumption is determined as:

$$a(t) = \frac{P(t)}{E(t)} \quad (6)$$

where $P(t)$ – the current volume of production made, $E(t)$ – the current volume of the energy consumed. Task (6) is incorrect because the current energy volume $E(t)$ is directed not to the current output of product $P(t)$, but to future product $P(t + \tau_3)$ due to inertia and delays in technological objects. It does not show the current power consumption. Far more reasonable and correct estimation is:

$$a(t) = \frac{P(t)}{E(t - \tau_3)} \tag{7}$$

where τ_3 is the technological process delay, but in this case estimation $E(t - \tau_3)$ is retrospective one, the resource is over. The prediction estimation can be used here:

$$a(t) = \frac{P(t + \tau_3)}{E(t)} \tag{8}$$

but marginally approximated model of the process (e.g., the delay link) is applied here. The statistic estimation

$$a_{cp} = \frac{P_{cp}}{E_{cp}} \tag{9}$$

is correct, but not operative one. It does not show the process of object dynamics.

The constructive approach is one that is based on the inverse models of object dynamics. These models are formed on the method of exponential filtering method. Formally, the object operator is presented in the fraction rational form with the delay link:

$$W(p) = \frac{\sum_{j=0}^{m} b_j p^j}{\sum_{i=0}^{n} a_i p^i} e^{-p\tau_3}, m < n, \tag{10}$$

where: a_j, b_j – the coefficients, $p = \frac{d}{dt}$ – the differentiation operator. Then, the inverse operator $W^{-1}(p)$ cannot be applied and it requires the implementation of extra mathematical methods, e.g., output signal analysis in polynomial basis. It is done to design the differential part with prognosis, which is a component of the inverse operator.

4 Discussion

Proactive estimations of dynamics can be applied to technical and economic indexes. For example, the current values of technical and economic indexes as well as their proactive values and cumulative estimation of resource saving are showed on the screen on system level.

Evaporator function in non-stationary modes and its evaporative capacity are described by the equation:

$$S_0(1 - \frac{CP_1}{CP_2}) = \frac{KF\Delta t}{\eta}, \tag{11}$$

where: S_0 – the amount of juice at input, [t/h]; CP_1, CP_2 – are correspondingly the content of dry matters in juice and syrup, [%]; K – the heat transfer coefficient, [W/m^{2}k]; F – is the heating surface, [m^2]; Δt – is useful temperature difference, [K]; η – is the vaporization heat.

In order to achieve the energy saving of evaporator control it is recommended to apply the well-known dependency of heat transfer coefficient on juice (syrup) level. This level is supported in different units ranging 35–60% from the heating surface length of tubes. It corresponds to the maximum value K. The methods of robust and extreme control are efficient in this case. The heat transfer coefficient change in 1, 5–2 times in the process of E functioning has also to be taken into account.

5 Conclusions

1. Energy saving control using evaporator implies considering its significance for the functioning in both technological and power heat complexes.
2. Heating vapor saving is possible provided that the levels of juice (syrup) in the units are supported when the heat transfer coefficient gets its highest value.
3. The system approaches and methods based on the existing technological and thermo technical requirements are recommended to use. The connections with other subsystems have to be taken into account as well: by losses (pumping) of juice with diffusive unit, by losses of secondary vapor with product unit (vacuum apparatuses).
4. The functional structure of evaporator automated system is developed on the methods of modern theory of control, information technologies which are implemented to optimization task solutions, situational, precedential and adaptive control. They are provided with information from subsystems of technological and energy monitoring.
5. The implementation of proactive control using time series, prognostic models, coordination algorithms, data base and knowledge creation for subsystems of decision making in terms of uncertainty and risks is a promising direction to increase the efficiency of sources of energy.

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