ISSN 2347 - 3983
Volume 8. No. 5, May 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter107852020.pdf
https://doi.org/10.30534/ijeter/2020/107852020

Determination and Estimation of the Influence of Different Types of Disturbances on the Thick Juice Colour to Apply in Automated Process Control Systems of the Sugar Mill Evaporator

Serhii Liashenko[1], Alla Fesenko[2], Oleksii Liashenko[3], Victor Kis[4], Heorhii Ivashchenko[5]
[1]Department of Life Safety and Law, Petro Vasylenko Kharkiv National Technical University of Agriculture, Ukraine, lyashenkosa05@ukr.net
[2] Department of Life Safety and Law, Petro Vasylenko Kharkiv National Technical University of Agriculture, Ukraine, alla.ecology3006@gmail.com
[3]Department of Computer Engineering and Control, Kharkov National University of Radio Electronics, Ukraine, oleksii.liashenko@nure.ua
[4]Department of Mechatronics and Mashine Elements, Petro Vasylenko Kharkiv National Technical University of Agriculture, Ukraine, vkisprof@ukr.net
[5]Department of Electronic Computers, Kharkov National University of Radio Electronics, Ukraine, heorhii.ivashchenko@nure.ua

ABSTRACT

The article considers the inefficient Ukrainian sugar mill operation and the influence of the evaporator automated process control system on energy efficiency of sugar beet production. Sugar production issues which decrease its competitiveness in Ukraine have been identified. Analysis about the impact of the major production departments has been carried out. The influence of the evaporator on the energy efficiency of the factory and on the quality of the products that must be competitive is proved. The study determined the influence of juice quality indicators during evaporation on the quality of sugar and the drawbacks in mathematical support of automated process control systems (APCS), which occur when evaporation conditions change.

The article shows the ways to solve issues that happen within decreasing the product quality and inadequate regulation of the production efficiency by means of APCS when the raw materials quality during evaporation has not been taken account. It determines the issues in the work of automated evaporation process control systems. Because of the complexity of juice evaporation in the multiple evaporation station and the influence of various process indicators both technological and qualitative we determine the main vectors of the management at automated process control systems of juice evaporation. To solve the issue, the major criteria of sugar production efficiency, regulatory requirements, theoretical foundations and the practical experience of implementation and the use of quality criteria in APCS in countries using the energy efficient and competitive technologies of sugar production are considered.

The efficiency of the proposed product quality criteria for mathematical support of automated evaporation control system is substantiated. Accordingly, there is reason to think that the obtained qualitative criterion of efficiency can be used in mathematical support of automated juice evaporation process control systems at the sugar factory.

Key words: automated process control system (APCS), efficiency criteria, mathematical model, multiple evaporation station (MES),technological process,quality indicators.

1. INTRODUCTION

Now we can see the rapid development of technologies, engineering, and information systems to support technological processes; so the sugar production competitiveness should meet modern requirements and advances in science. It is really important because sugar production is one of the most energy intensive and complex, which is key issue when energy resources have a high cost. Additionally, the product quality is crucial to improve the profitability of the industry. To increase the efficiency of sugar mill operation, it is advisable to supplement automated control systems with models, methods and algorithms for diagnosis and forecasting, which will allow the real-time operational detection, recognition and prediction of changes in the technological process. It is also important to find, justify and implement corrective actions in the automated processes control system, which helps to make the production competitive, to ensure product quality [1].

Modern high efficient sugar production is described, first of all, with such indicators as quality, energy efficiency, and cost. Achieving these effective indicators is ensured by the use of the latest production technologies, equipment, automated process control systems, computerization of production processes, and the organization of sugar production as well. Nowadays, in a market economy, continuous high-power technological processes prevail with complex energy and material flows and strict requirements of product quality, occupational safety, equipmentpreservation, and environmental friendliness. All that leads to the need to create modern effective management systems, especially optimal.

One of the most important parts of sugar production is a sugar factory, which consists of such important sections that use continuous processes with energy and thermal components as diffusion, juice purification, evaporation and crystallization. The main department that affects the energy efficiency of awholesugar factory is the evaporatorthat receives and distributes steam to other departments [2].

In technological processes of a continuous type like sugar mills there are complex technological objects, which are described with many interconnected technological processes (TP). This is applied, for example, to the multiple evaporation stations of the sugar mill (MES).

The MES evaporates thin juice to a desired concentration, provides heat exchange equipment with secondary steam not only in the evaporation station, but also in other departments of the mill. Thus, one of the main tasks of the MES is to obtain at the output from the evaporator concentrated juice with the concentration that is necessary to get the qualitative products with desired contents of dry matter, pH, and so on. The low quality of the resulting juice requires additional quantity of steam for the crystallization process in vacuum devices in the crystallization department .

So, the main tasks of the evaporator management are: the maintenance of the required technological mode with fixed indexes of the technological process, the stabilization of juice levels in the evaporators, the obtaining the required colour of juice and providing users with steam.

Accordingly, the major issues intheevaporation station operation thatmustensure the production effectiveness are:
– to ensure the quality of raw materials, which must meet the calculated values at all stages of the production, including evaporation. It should guarantee the evaporation efficiency throughout the technological process;
– the dynamism of the juice concentration changes during the MES operation, which is caused by time-varying quality parameters of boiled juice and variable indicators of heat and mass transfer processes;
– the inconsistency of APCS response to the changes of evaporation;
– the complexity and capacity of engineering calculations of the thermal evaporation used in APCS (for instance, application of approximate criteria and tabular values in the calculation of thermal parameters to constantly changing evaporation process);
– the effective mathematical support in APCSs for evaporation.

In order to obtain competitive sugar products in Ukraine, it is necessary to bring the requirements for sugar quality in line with European regulatory requirements and the requirements used in countries with a developed sugar industry [3, 4].

The low quality of thick juice is one of the main reasons for the deterioration of the sugar quality, in particular the higher content of ash and increased colour.

It is known that to get high quality sugar, the purity of thick juice must be at least 92 %. The value of the thick juice purity depends on the quality of processed beets, the parameters of sugar extraction and diffusion juice purification. If mistakes were made in extraction of sucrose and purification of juicethenit is almost impossible to correct at the last stages [1].

The sugar colour is described with substances that are formed in the production process during storage of the products. It is an important feature of the product quality. The colour depends on the ability to absorb or reflect the rays of visible light. The depth of light absorption reflects the color intensity of the product. The main groups of colourants are: melanoidins, products of acid-base sugar decomposition and the products of carbohydrates caramelization [5].

The high juice colour can take place:
– at processing of low qualitative beets;
– in case of poor operation in the diffusion department (low quality of chips, higher temperature, high microbiological contamination of juice, etc.);
– due to unsatisfactory operation of the purification department (the optimal parameters for defecation are not observed: temperature, process duration, etc.);
– in case of deviation of the MES mode: low supply of the II saturation juice, the required level of juice in the evaporators is not maintained, the long stay of juice in the MES.

And if the first three components that affect the juice color must be controlled and corrected in the departments of diffusion, processing and purification, the last component, which also affects the quality of the product, refers to the evaporation department.

The colour during enriching juice depends on:
– quality of juice enriching
– technological mode of operation at the MES;
– designs of evaporator vessels.

A significant increase in color is observed during enriching the low quality juice, especially containing a significant amount of reducing substances. This occurs in the processing of low quality beets and insufficient decomposition of reducing substances in the process of lime - carbon dioxide cleaning. The next stage, the decomposition of reducing substances in the evaporator, in the presence of nitrogenous substances, at elevated temperatures, as a result of the Mayar reaction leads to the formation of intensive colourants - melanoidins. They intensively include in sugar crystals and mainly increase the colour of sugar.

In case of deviations that take place in the technological processes before the juice evaporation, the heating surface of the evaporator will ignite. In this case, the time of juice stay in the evaporator's increases and, accordingly, the amount of the decomposing sucrose rises and the colour increases.

When juice has the same quality the colour increase depends mainly on maintaining the optimal parameters of evaporation, namely: maintaining the steam pressure, the juice level in the evaporators of the MES, uniform supply of juice to the evaporation station, temperatures in the evaporators and so on. The deviation of these parameters from the optimal values affects the duration of the juice staying in the evaporators and its temperature, which determines the colour increase. Both of these factors affect the sucrose decomposition. The less juice is in the evaporator, the less sucrose decomposes and the less the colour increases.

The time of juice stay and the evaporation temperature depend also on the design and operation principle of the used evaporators and their arrangement in the scheme of the evaporation station.

An important factor influencing the quality of the evaporated juice is also the scale formed on the heating surface of the evaporator. The scale significantly reduces the evaporator heat transfer rate, leads to a decrease in equipment productivity, increases the time of juice stay and raises the colour.

The influence of the scale is decreased by using various chemical substances that minimize the scale formation in the evaporator. It is very important to increase the product quality and improve the sugar quality.

The dynamism of juice changes in the MES operation is reflected in physico-chemical nature of evaporation. Evaporation is based on the ability of a solvent to evaporate (to pass from liquid to vapor phase) depending on the physico - chemical properties of the solvent, the temperature of the solution and its concentration. During evaporation there is an exchange of energy (heat) between the coolant and the solution, which results in the transition of part of the solvent from liquid to vapor phase.

The first stage of the evaporation is the supply of the required amount of heat to the solution. During evaporation, as a kind of heat transfer process, the driving force of heat transfer is the temperature difference between the heating steam and the boiling point of the solution.

The next step of the evaporation is the interfacial exchange of matter (mass) associated with the phase transitions of the liquid phase to the vapor (for the solvent) or from the liquid phase to the solid (for the solution during its concentration and crystallization). Such processes are mass transfer. The driving force of evaporation is the difference between the saturated vapor pressure of the solvent in the liquid phase at the solution temperature and the vapor pressure of the solvent in the vapor phase at its saturation temperature. As a rule, the process of the solution evaporation needs the solvent vapor pressure in the solution higher than the solvent vapor pressure over the solution in the vapor space.

Accordingly, based on the evaporation nature, it should be noted the need to control the technological parameters (pressure, temperature, concentration, colour, etc.), which constantly change depending on changes in the solution during evaporation .

The complexity and capacity of engineering calculations of the thermal evaporation used in APCS is you need to know a large number of indicators that will be used to determine the required parameters of evaporation, such as thermal properties of juice, juice flow, juice temperature, steam pressure, etc.

For the thermal calculation of the evaporation process, which includes determination of the heat transfer surface area of the evaporators and the steam consumption, a quite complex calculation method is used. The calculation method refers to the steam consumption for preheating the inlet solution, water evaporating in the evaporators, the concentration of the solution in the stages of MES, the useful temperature difference in the evaporators, the preliminary distribution of the required temperature difference in the evaporators, heat transfer rates, etc. In addition, the engineering calculations of the evaporation process use a large number of different criteria (of Reynolds, Nunselt, etc.) and the average values and dependencies.

Based on the above, it can be noted that the method of the calculation and the large number of the used indicators make it difficult to determine the actual evaporation indexes, which, in turn, reduces the efficiency of the evaporation process and operation of APCS [2, 6].

Effective mathematical software in APCS in the evaporators is used mainly to solve the issues of determining the effective quality functional. The optimalprocesscontrol systems were developed by such scientists as A. Kolmogorov, N. Wiener, R. Belman, R. Kalman, V. Glushkov and others. Based on the theory of optimal control, methods of constructing systems with optimal speed and procedures of analytical design of optimal regulators were implemented.

Nowadays, in contrast to the classical control theory which studies one-dimensional systems described with linear differential equations with constant coefficients, the modern control theory applies the results used for different classes of multidimensional systems that can be given with different types of equations.

The modern control theory includes the theory of optimal control, i.e the optimal systems, the operation of which minimizes or maximizes a given quality functional. In addition, an important issue in determining the effectiveness of evaporation is the definition of control criteria.

Having analyzed the effectiveness of the main directions in the production and processing of sugar to bring sugar quality indicators in Ukraine to international requirements, we can conclude that to achieve this aim it is necessary to solve a range of issues at all stages of sugar production.

At the same time, one of the major ways to increase the quality is improvement of APCS in the evaporation department, which helps bring closer the juice quality to the normative. It will allow obtaining the standard sugar quality at the last stage of sugar production, in the product department. Construction and application of effective models to APCS that respond to changes in the evaporators will provide an opportunity to increase the production efficiency, energy efficiency and the product quality.

The aim of the study is to increase the efficiency of the multiple evaporation station at the sugar mill by developing and applying modern criteria and mathematical models of determining the juice quality in automated control system.

To achieve this aim, the following tasks were identified: analysis and justification of the application of relevant juice quality criteria; assessment and identification of the impact of various disturbances that occur during evaporation on the product quality to use in APCS of the evaporator.

2.METHODOLOGY

2.1Analysis and substantiation to apply relevant effective juice quality criteria in APCS of the sugar mill evaporator

In the framework of the Association Agreement between Ukraine and the European Union and the implementation of the Action Plan for the implementation of the Association Agreement between Ukraine, on the one hand, and the European Union, the European Community and their Member States, on the other hand, for 2017-2019, Ministry of Agrarian Policy of Ukraine introduced of Council Directive 2001/111 / EC of December, 20, 2001 on certain types of sugar for human consumption.

The issue of sugar quality is interrelated with advanced technologies, modern automation systems and computerization of production processes. Therefore, the solution to the issue of improving the sugar quality is also related to the production efficiency. The major indicators of sugar quality are the content of sucrose, ash, reducing substances, the moisture and the colour [3, 4].

The major quality indicator of sugar is the colour. It is used by the European Community and by countries that are efficiently engaged in sugar production, as well as in accordance with DSTU 4623: 2006. According to these requirements, a normative value of the colour in juice to the 1st category sugar is not more than 45 ICUMSA units, to the 2-nd category is 60, to the 3rd category is 104, and to the 4th category sugar is not more than 195. In accordance with the Order of Ministry of Agrarian Policy from November 02, 2017 № 592 "On approval of the Requirements for types of sugars intended for human consumption", the major quality indicators of sugar that meet international requirements has been introduced. It says that the colour in solution, for the category "extra white sugar" should be not more than 22.5 ICUMSA units. The analysis of the quality requirements to sugar and the prospects of ways to improve the efficiency of the sugar production are given in following works [7, 8].

At the sugar mills, the multiple evaporation station like the other production departments operate in uncertain conditions that, in turn, are divided according to the uncertainty of thepurpose, the uncertainty of the external environment and the uncertainty of the decision-maker. The basis of the efficiency of the evaporation process is the correct definition of the purpose. The uncertainty of the purpose consists of incorrect setting of the criterion of functioning. In most cases, the criterion of management at the MES is taken as the minimum energy cost, i.e the minimum steam consumption. As the quality indicators, the minimum standard deviation of the thick juice concentration at the outlet of the evaporator is determined.

But such a criterion setting leads to incomplete consideration of those parameters that are included in the restrictions, and therefore, to the lack of secondary steam for users, to inexpedient excess of steam consumption, etc. So the most complete criterion for the functioning of the MES should be a convolution all of these. But the non-stationary operation of the MES, caused by time-varying parameters of the boiled juice and variable indicators of the heat and mass transfer evaporation processes, complicates the determination of this general criterion and reduces the efficiency of it.

Typical disturbances that lead to non-stationary work are divided into external and internal one.

All of these disturbances leading to both non-stationary operation of the MES and the evaporation time increase cause growth in such a qualitative indicator as the colour.

Determination of the time of juice stay in the MES of different designs and operating conditions is one of the most important features of their work, which affects the colour. Theoretically, the determination of the time of juice stay in the MES is based on the physical laws of evaporation that consists in the thermal concentration of solutions during boiling and partial removal of water in the form of steam.

The dependence of the amount of sugar loss on thermal decomposition is close to linear over time. This means the dependence is generally nonlinear but the operating parameters of the process are located at the beginning part of the exponential function curve, where it is very close to linear. That is why the linearity of the thermal decomposition of sucrose in dependence from the time of the process simplifies the task of its determination by using the average time of juice stay, which is defined as the ratio of the volume of juice consumption ($\mathbf{V_{jc}}$) to the value of the juice contained in the evaporator ($\boldsymbol{V_e}$)

$$\boldsymbol{\tau} = \frac{\mathbf{V_{jc}}}{\mathbf{V_e}} \qquad (1)$$

whereτis duration of the reaction.

Increasing both the evaporation time and the boiling point leads to an increase in sugar loss from thermal decomposition and a growth in the colour of juice. The increase in sugar substances and the sugar loss correlate with each other.

Accordingly, knowing the volume loss of the solution from the MES, and its density, it is possible to determine the average time of juice stay in each evaporator, and accordingly in the entire MES. According to the results of calculations by using formula (1), the standard time of juice stay in the MES at the sugar mill with a capacity of 3000 tons of beets per day and with heat transfer areas in the stages of the MES are: 1 stage – 2360 m^2, 2 stage – 3000 m^2; 3 stage – 2360 / 1200 m^2, 4 stage – 1200 m^2; 5 stage – 100 m^2. All of them are shown in table 1. For comparison in table 1 are also shown the values of the real modes of operation at the MES with different types of disturbances, and pH of the evaporating juice. They result in a change of the quality criterion, the colour.Inaddition,table 1 shows the juice colour for these modes of the MES operation (normative and real) before and after the evaporation process.

Table 1: The average values of evaporation time and the color at the MES of sugar mills with a capacity of 3000 tons of beetsper day

Type of evaporation mode	The colour of thin juice before the evaporator, ICUMSA units	Evaporat ion time, minutes	The colour of thick juice after the evaporator, ICUMSA units
Normative (calculated)	220–260	50–60	250–300
Real	280–450	101–118	320–700

Analysis of the obtained normative (calculated) and real types of evaporation in the MES (with different types of disturbances: the acidity (pH), the dry matter (DM), the temperature, etc.) for different operation durations and the colour shows that the colour increases on average by 30-50%. At the same time, the normative and real values of the colour describe 4 qualitative groups of sugar and, accordingly, juice before and after the MES. The pH values before and after the MES have ranged from 8.3 to 9.1; and the DM is from 14% to 68%. During evaporation, different types of chemicals were used to purify juice in the evaporator as well as different types of juice filtration before.

The colour after the evaporator can increase up 900 ICUMSA units at considerable infringements of the operating mode [9].

2.2 Determination and estimation of the influence of different types of disturbances during evaporation on the juice colour for using in APCS of the sugar mill evaporator

To obtain competitive sugar, it is necessary to pay attention to the major indicators of efficiency: the energy saving and the sugar quality. These indicators in operation of the evaporator are the steam consumption and the colour according to regulatory requirements. So the efficiency of the evaporator depends primarily on the use of an effective system of automation at the evaporator, which should be based on mathematical software that will apply modern quality criteria, mathematical models and relevant engineering calculations [10]. The calculations should use effective theoretical ways to reflect the real evaporation process.

It is necessary to pay attention to disturbances that occur during evaporation and affect the real indicators of evaporation.

To determine the influence of various factors on the evaporation of water from juice in the evaporator we consider the equation of material balance, which has the form [1, 2]

$$G_b = G_f + W, \quad (2)$$

where G_b– productivity for beginning juice, kg / h;
G_f– productivity for final juice, kg / h;
W – a total amount of evaporated water, kg / h.

The solution that evaporates in the evaporator should retain the equality of the solid mass, which is determined with such correlating indicators as the sugar content, colour, turbidity, and so on. As one of the main criteria for sugar production, in accordance with regulatory requirements, is the colour (Co) in ICUMSA units, and during evaporation,both the content and colour change; so the equality of the solid mass can be displayed as following [11]

$$G_b Co_b = G_f Co_f, \quad (3)$$

whereCo_b and Co_f – the beginning and final juice colour, ICUMSA units.

Using formulas (2) and (3), we can determine the total amount of water W_t that evaporates at the required colour to obtain the quality sugar

$$W_t = G_b\left(1 - \frac{Co_b}{Co_f}\right). \quad (4)$$

The sugar content and the colour of the juice are correlated, and in accordance with the approved method given in DSTU 4866: 2007 / GOST 12572-2007, the colour of sugar juice is determined with the formula

$$Co = \frac{1000 \cdot D_{420}}{c \cdot l}, \quad (5)$$

where$c$ – a sugar content, g/dm^3
D_{420}–the value of the juice optical density at a wavelength of 420 nm;
l–thelengthof the cuvette, cm (for thick juice eguals 5 cm);
1000 – thecolour conversion factor in ICUMSA units.

If c is determined by means of the following formula

$$c = \frac{DM \cdot \rho}{100}, \quad (6)$$

then the formula to determine the colour can be displayed as follows

$$Co = \frac{100 \cdot 1000 \cdot D_{420}}{DM \cdot \rho \cdot l}, \qquad (7)$$

where DM – the dry matter in juice, %
ρ – density of the juice, g/cm^3
100 — a coefficient to transfer percent in grams.

Having determined the dependence of the colour and the sugar content on the evaporated water to adjust the thick juice color after evaporation, we need to determine the sensitivity of APCS in the evaporator to disturbances forming as a result of the effect of heat expended on evaporation and the productivity and composition of thin juice before evaporation. From equation (4) we can determine the product quality, which looks as

$$Co_f = \frac{Co_b}{1-\frac{W_t}{G_b}}. \qquad (8)$$

Having differentiated by $\frac{W_t}{G_b}$ we obtain the sensitivity of the colour change to the ratio of the evaporated water amount to the thin juice productivity as in the following proportion

$$\frac{dCo_f}{d\left(\frac{W_t}{G_b}\right)} = \frac{Co_b}{\left(1-\frac{W_t}{G_b}\right)^2} = \frac{Co_f^2}{Co_b}. \qquad (9)$$

The expression of the differential due to the colour more accurately shows the sensitivity to different types of disturbances during evaporation. As a result, expression (9) has the form

$$\frac{dCo_f}{d\frac{\left(\frac{W_t}{G_b}\right)}{\left(\frac{W_t}{G_b}\right)}} = \frac{Co_{fK}(Co_f - Co_b)}{Co_b} \qquad (10)$$

3. RESULTS AND DISCUSSION

Substituting the values of the proposed criterion, the colour, in the formula (10), we obtaine that the juice colour changes during evaporation by ∓1.1 – 1.5 % from required 300 ICUMSA units (if we consider the 1st category sugar according to table 1). The obtained values of the qualitative index impact indicate that the proposed approach with using a quality criterion is quite effective. It can be applied in APCS of sugar production.

The proposed qualitative criterion of the evaporation effectiveness given in formula 8 has been included into the corresponding algorithm of movement and the order of data application in the thermal calculation of evaporation for mathematical support of APCS of the evaporator. This algorithm is shown at Fig.1.

All informational indexes I (measured and calculated) from the displayed databases in Fig. 1 (A, B, C, E) provide information to the database D for processing and calculation of the thermal mode of the evaporator operation at the certain time.

Entering indicators the database D with the appropriate data and the results of laboratory tests and calculations, as well as the features of the thermal modes of the evaporator on the PC helps to take into account the changes in operation of the evaporator and adjust the thermal calculation of the operating modes applying a new quality criterion, the colour. The obtained data is directed to the controller K, from where the corrected data is directed to the database A to adjust the input values, and to the database E to control evaporation by changing the heat load of the evaporators.

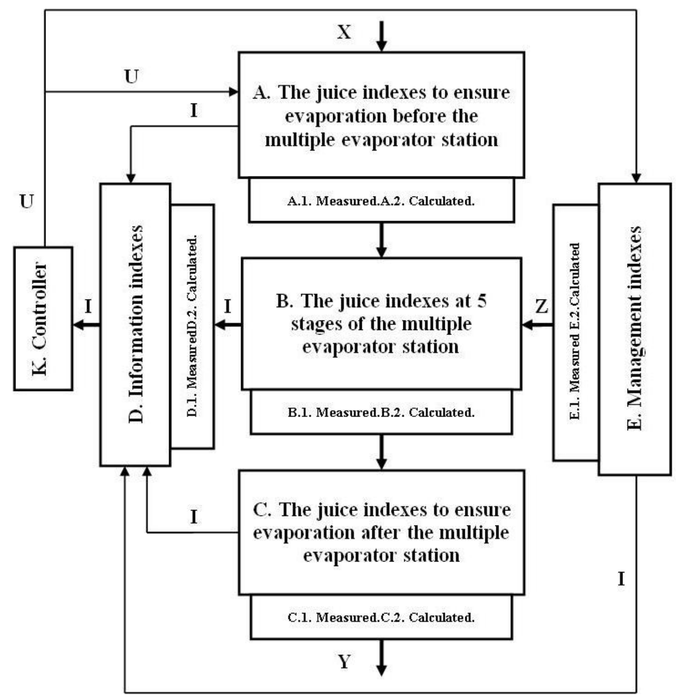

Figure 1: Algorithm of movement and the order of data application in the thermal calculation of evaporation for the mathematical support of APCS of the evaporator: X is the input vector; Y is the output vector; U is the control vector; Z is the vector of disturbances; I is the information vector; A is the information indicators for APCS before the evaporator; B is the information indicators from the object to management by APCS; C is information indicators for APCS after the evaporator; D is processing of the information indicators; E is information values of management indicators; K is a controller

4. CONCLUSION

The paper analyzes the effectiveness of existing approaches to mathematical support of APCS for evaporation, which is a promising way to increase the competitiveness of sugar production. The types of disturbances that occur during evaporation of water from thin juice and their impact on the production efficiency have been considered. Authors propose to use qualitative indicator of the colour both for sugar production and for evaporation. It is applied in countries with highly developed sugar production. The influence of duration of evaporation in the evaporator and different types of disturbances on the colour as a quality indicator has been obtained. In addition, using the proposed qualitative efficiency criterion, authors have received the dependence of this criterion on such disturbance indicators of evaporation as the heat load, juice productivity and juice quality before the evaporator. It can be used in APCS to provide optimal mode of the evaporator operation. The algorithm of movement and the order of data application in the thermal calculation of evaporation for mathematical support of APCS of the evaporator have been offered. The obtained results about determination of the influence of disturbances on the qualitative index have showed the effectiveness of the proposed approach. It can be applied in the system of mathematical support of APCS at the evaporator. Further development of automated control systems in sugar production can be based on the principles of artificial intelligence and fuzzy logic [12, 13].

REFERENCES

1. Lajos Rozsa. **A few thoughts on automation in sugar manufacturing,** *International Sugar Journal*, vol 106, no. 1252, pp. 156-166, April 2003.
2. Maria P. Marcos, Jose L. Pitarch, Christian Jasch, Cesarde Prada. **Optimal distributed load allocation and resource utilisation in evaporation plants,** *Computer Aided Chemical Engineering*, vol. 46, pp. 979-984, 2019. https://doi.org/10.1016/B978-0-12-818634-3.50164-8
3. **DSTU 4623-2006. National standards of Ukraine. White sugar. Technical conditions**, Kyiv, 2007.
4. Ensinas A. V., Nebra S. A., Lozano M. A., Serra L. **Design of Evaporation Systems and Heaters Networks in Sugar Cane Factories Using a Thermoeconomic Optimization Procedure,** *Int. J. of Thermodynamics*, vol. 10, no. 3, pp. 97–105, 2007.
5. Christopher P. East, Christopher M. Fellows, William O. S. Doherty. **Chapter 25 - Scale in Sugar Juice Evaporators: Types, Cases, and Prevention.** *Mineral Scales and Deposits. Scientific and Technological Approaches*, pp. 619-637, 2015, doi:10.1016/B978-0-444-63228-9.00025-5
6. Kovalenko A., Shamraev A., Shamraeva E., Dovbnya A., Ilyunin O. **Green Microcontrollers in Control Systems for Magnetic Elements of Linear Electron Accelerators.** *Green IT Engineering: Concepts, Models, Complex Systems Architectures. Studies in Systems, Decision and Control series. Springer International Publishing Switzerland*, pp. 283-305, 2017. doi:10.1007/978-3-319-44162-7_15
7. Somchart Chantasiriwan**. Increased Energy Efficiency of a Backward-Feed Multiple-Effect Evaporator Compared with a Forward-Feed Multiple-Effect Evaporator in the Cogeneration System of a Sugar Factory**, *Processes*, vol. 8 no. 3, p. 342, 2020, doi:10.3390/pr8030342
8. Alejandro Merino, Luis Felipe Acebes, RaúlAlves, César de Prada. **Real Time Optimization for steam management in an evaporation section**, *Control Engineering Practice*, Volume 79, Pages 91-104, October 2018, doi:10.1016/j.conengprac.2018.07.010
9. Reva L., Vygovskyi V. **Improvement of the quality and yield of sugar by using of adsorption purification of syrup in the modern technological scheme**, *in Proc. International Scientific-Technical Conf. Prospectives of Ukrainian sugar production development*, Kyiv, pp. 89-96, 2019,
10. A. Satif, L. Hlou, H. Dahou, M. Mekhfioui, R. Elgouri. **Grid-connected photovoltaic systems synchronization algorithms under disturbances: a low-cost hardware implementation using Arduino DUE,** *International Journal of Emerging Trends in Engineering Research*, vol. 8, no. 3, pp. 674-682, March 2020, doi:10.30534/ijeter/2020/11832020
11. Christopher D. Rhoten.**Influence of sugar and syrup pH value on overall color rise in the sugar end and color of final molasses**, *Sugar Industry*, pp. 527 – 532, 2011, doi:10.36961/si11854
12. O. Liashenko, O. Barkovska, Ch. Al-Atroshi, O. Datsok, S. Liashenko. **Model of the Work of the Neurocontroller to Control Fuzzy Data from the Sensors of the Climate Control Subsystem "Smart House",** *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 8, no. 1.2, pp. 70-74, 2019, doi:10.30534/ijatcse/2019/1281.22019
13. Aaron Don M. Africa, Patrick Bernard T. Arevalo, Arsenic S. Publico, Mharela Angela A. Tan. **A Fuzzy Neural Control System,** *International Journal of Emerging Trends in Engineering Research*, vol. 7, no. 9, pp. 323-327, September 2019, doi:10.30534/ijeter/2019/15792019