ISSN 1815-4840
E-ISSN 2181-1105

КИМЁВИЙ ТЕХНОЛОГИЯ
НАЗОРАТ ВА БОШҚАРУВ

ХИМИЧЕСКАЯ ТЕХНОЛОГИЯ
КОНТРОЛЬ И УПРАВЛЕНИЕ

CHEMICAL TECHNOLOGY CONTROL AND MANAGEMENT

International scientific and technical journal 1/2023

CHEMICAL TECHNOLOGY. CONTROL AND MANAGEMENT

2023, №1(109)
International
scientific and technical journal
Since 2005

Founders:
TASHKENT STATE
TECHNICAL UNIVERSITY,
SSC «UZSTROYMATERIALY»,
SSC «UZKIMYOSANOAT»,
JV «SOVPLASTITAL»,
AGENCY ON INTELLECTUAL
PROPERTY OF THE REPUBLIC OF
UZBEKISTAN

The Chief Editor and Chairman of the Editorial Board:
YUSUPBEKOV Nadirbek Rustambekovich

Assistants:
GULYAMOV Shukhrat Manapovich,
IGAMBERDIEV Khusan Zakirovich,
ADILOV Farukh Tulkunovich.

The Executive Secretary:
MATYOKUBOV Nurbek Rustamovich
KASIMOV Farkhod Orifjanovich
SHODIYEV Ma'rufjon Kobuljonovich

Our address:
Tashkent 100095,
Universitetskaya str., 2
Phone:
71-227-17-16
Journal Homepage:
https://ijctcm.researchcommons.org/journal/
E-mail:
app-tgtu@mail.ru

CONTENTS

CHEMICAL TECHNOLOGY

CONTROL OF TECHNOLOGICAL PARAMETERS

MANAGEMENT OF TECHNOLOGICAL PROCESSES

INFORMATION TECHNOLOGY. INFORMATION SECURITY

Chemical Technology, Control and Management

Volume 2023 | Issue 1 Article 11

2-28-2023

VIRTUAL POTASSIUM CHLORIDE ANALYZER IN THE SYSTEM OF ADVANCED CONTROL OF POTASH FERTILIZER PRODUCTION PROCESSES

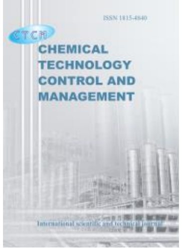
Umidjon Ruziev
Tashkent State Technical University named after Islam Karimov. Address:100095, Tashkent, Republic of Uzbekistan, Universitetskaya str.

Jahongir Sherboyevich Bekqulov
Tashkent State Technical University named after Islam Karimov. Address:100095, Tashkent, Republic of Uzbekistan, Universitetskaya str. E-mail: jbekqulov@mail.ru, Phone:+998-99-081-09-55., jbekqulov@mail.ru

Recommended Citation

Ruziev, Umidjon and Bekqulov, Jahongir Sherboyevich (2023) "VIRTUAL POTASSIUM CHLORIDE ANALYZER IN THE SYSTEM OF ADVANCED CONTROL OF POTASH FERTILIZER PRODUCTION PROCESSES," *Chemical Technology, Control and Management*: Vol. 2023: Iss. 1, Article 11.
DOI: https://doi.org/10.59048/2181-1105.1427

ISSN 1815-4840, E-ISSN 2181-1105
Himičeskaâ tehnologiâ. Kontrol' i upravlenie
CHEMICAL TECHNOLOGY.
CONTROL AND MANAGEMENT
2023, №1 (109) pp.80-88
International scientific and technical journal
journal homepage: https://ijctcm.researchcommons.org/journal/



Since 2005

Article history: Received 28 December 2022; Received in revised form 24 February 2023; Accepted 28 February 2023; Available online 23 March 2023

VIRTUAL POTASSIUM CHLORIDE ANALYZER IN THE SYSTEM OF ADVANCED CONTROL OF POTASH FERTILIZER PRODUCTION PROCESSES

U.Ruziev[1], Zh.Sh.Bekkulov[2]

[1,2]Tashkent State Technical University named after Islam Karimov. Address:100095, Tashkent, Republic of Uzbekistan, Universitetskaya str.
E-mail: [2]jbekqulov@mail.ru, Phone:+998-99-081-09-55.

Annotation. *It is proposed to include virtual instrumental quality analyzers of potash fertilizers in the composition of the advanced (advanced) management system. The structure of the virtual analyzer is substantiated using mathematical models of the technological process of drying potassium chloride in its composition. Based on the results of fuzzy clustering, the parameters of the modes of the technological process of drying potassium chloride are determined.*

Keywords. *Virtual analyzer, drying, potassium chloride, APC-advanced (or advanced) control system.*

Аннотация: *Калийли ўғитларнинг такомиллашган бошқариш тизими таркибида ўғит сифатининг виртуал инструментал анализаторини қўшиш таклиф этилган. Виртуал анализаторнинг таркибида калий хлоридни қуритишнинг технологик жараёнини математик моделларидан фойдаланиб, унинг стурктураси асосланган. Ноаниқ кластерлаш асосида калий хлоридни қуритиш технологик жараёнининг режим параметрлари аниқланган.*

Таянч сўзлар: *виртуал анализатор, қуритиш, калий хлорид, APC – такомиллашган бошқариш тизими.*

Аннотация. *Предложено в состав системы усовершенствованного (продвинутого) управления включать виртуальные инструментальные анализаторы качества калийных удобрений. Обоснована структура виртуального анализатора с использованием в его составе математических моделей технологического процесса сушки хлорида калия. На основе результатов нечеткой кластеризация определены параметры режимов технологического процесса сушки хлорида калия.*

Ключевые слова. *Виртуальный анализатор, сушка, хлористый калий, APC-система усовершенствованного (или продвинутого) управления.*

Introduction

At all times, the determination of the quality of mineral fertilizers is of lasting importance. The history of testing mineral fertilizers has come a long way. The number of methods and determined parameters of fertilizer quality has been constantly increasing, and the methods themselves have been constantly improved - mainly by involving well-founded physical and chemical principles in the testing procedure and the associated development of an instrument-analytical base [1].

Recently, testing methods include many complementary procedures that provide opportunities to fix the quality of mineral fertilizer and optimize its properties for different consumers. The persistence of environmental and quality requirements of the international community and, above all, the European Union for fertilizers consumed may lead to a reduction and tightening of the export opportunities of the domestic chemical industry. In this regard, the goal of ensuring a world-class quality of domestic mineral fertilizers is becoming increasingly relevant. And one of the most important tasks in achieving this topical goal is to manage the quality of fertilizers produced, which can be traced at all stages of its life cycle [2].

One of the main tools of advanced control systems is a virtual analyzer (BA), which is a software and algorithmic complex designed to implement operational measurement of quality indicators of technological processes (TP) or manufactured products based on the values of other measured parameters. Many works have been devoted to the development of virtual analyzers in the industry [3-7]. The simplest type of virtual analyzers that can be used to measure product quality indicators in technological processes is shown in Fig.1.

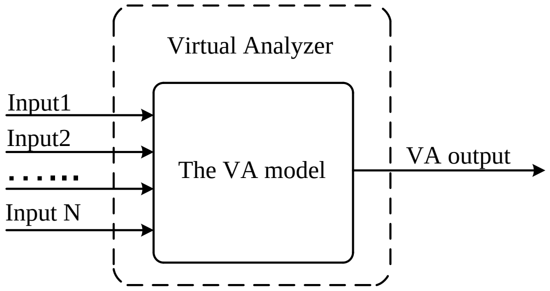


Fig.1. ***Diagram of the structural construction of the virtual analyzer.***

The values received at the input of virtual analyzers are parameters measured and controlled by instruments. The output of the virtual analyzer is an indicator of the quality of technological processes or manufactured products.

At the present time, the error of measuring the net weight of mineral fertilizers allowed by state stations is 0.1-0.4%. However, with multiple accounting of the same batches of fertilizers in the system from the enterprise to the consumer, the total error can reach 2-3%. The losses of the country's budget from such errors are comparable to large income items. The solution to this problem can be the modernization and improvement at the accounting nodes of the system for measuring the quantity and quality indicators of mineral fertilizers.

Methods and algorithms for the production of mineral fertilizers and the construction of virtual quality analyzers

The reality of today's industrial enterprises is their transfer to new automation equipment with the development and implementation of so-called advanced (or advanced) control systems with virtual analyzers in their composition, which are focused on using all the potential capabilities of microprocessor technology and on achieving a deliberately large technological and economic effect. At the same time, one of the main trends in the development of Advanced Process Control and Optimization System (APC)–systems of advanced (or advanced) control and optimization - is the spread of the more modern achievements, robust and intelligent control [8].

One of the stable trends in the development and improvement of modern systems of advanced management of chemical and technological processes and productions consists in the use of virtual analyzers of the quality of final industrial products, which are mathematical models of various structures used both as part of automated control systems of advanced process control, and as software tools for informing operational dispatching personnel, managing technological processes.

Accordingly, a wide range of traditional algorithms and methods of data analysis and modern automatic control theory can be used in virtual analyzers, as well as neural networks, fuzzy logic, kinetic algorithms, etc. If the accuracy and efficiency of identification analysis turns out to be satisfactory according to the selected criterion, then the models obtained with the help of a virtual analyzer can be used in real advanced control systems. Virtual analyzers can also be used to support decision-making by the operator of a technological installation - as an application to control systems that form a forecast of product quality indicators in the mode of real operation of the technological process.

Accurate maintenance of product quality indicators is of great importance in the technological processes of potash fertilizers production. These indicators are characterized by the complexity of measurement. The chromatographic method is used to measure the content of potassium chloride. At the same time, the measurement results are known at discrete points in time, which lag behind each other throughout the entire cycle of the chromatograph. The block diagram of the system for automatic measurement and adjustment of the product quality parameter is shown in Fig.2.

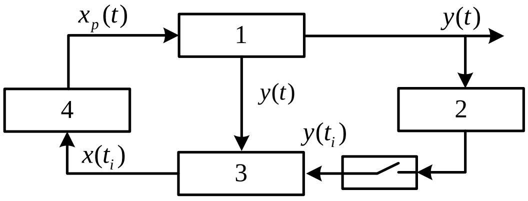


Fig.2. ***Block diagram of the system for automatic measurement and adjustment of the product quality parameter:*** *1 - Object, 2 - virtual quality analyzer, 3 - computing device, 4 - controller.*

The measurement process can lead to many additional delays and to a decrease in the dynamic accuracy of the setting. To reduce the effect of delay on the scale, a quality dependency model is used with variable product parameters that are measured continuously. This model can be much simpler; the values of the quality parameters are compared with the calculated coefficients of the model. Thus, one of the most common ways to adjust the quality is to determine the algorithm of its calculation based on indirectly calculated indicators directly based on the results of the analysis.

Therefore, in the practice of industrial production of potash fertilizers, the determination of the moisture content of potassium chloride after drying is periodically carried out by laboratory analysis of the samples obtained. For the task of constant monitoring of the quality indicator, it is proposed to use a virtual analyzer, which is a software package that implements a mathematical model of the relationship between the quality indicator and the current values of the measured process parameters. A virtual analyzer is an analytical and empirical relationship between the parameters of the drying process and the product quality index, including analytical models and statistical models based on artificial neural networks [9-16]. Virtual analyzers independently form the basis of a certain cycle of automation of the technological process and allow you to see the concentration of the components of the substance on the display screen.

In all areas of production, measurement and quality control of products can be determined without any tools using laboratory analysis or mathematical models based on the measurement principle of a virtual analyzer [13]. For this reason, virtual analyzers are called “intelligent sensors". In addition, the advantages of virtual analyzers are that the application model is configured in real time to control the process based on technological data extracted from the knowledge base. The scheme of building a virtual analyzer is shown in Fig.3.

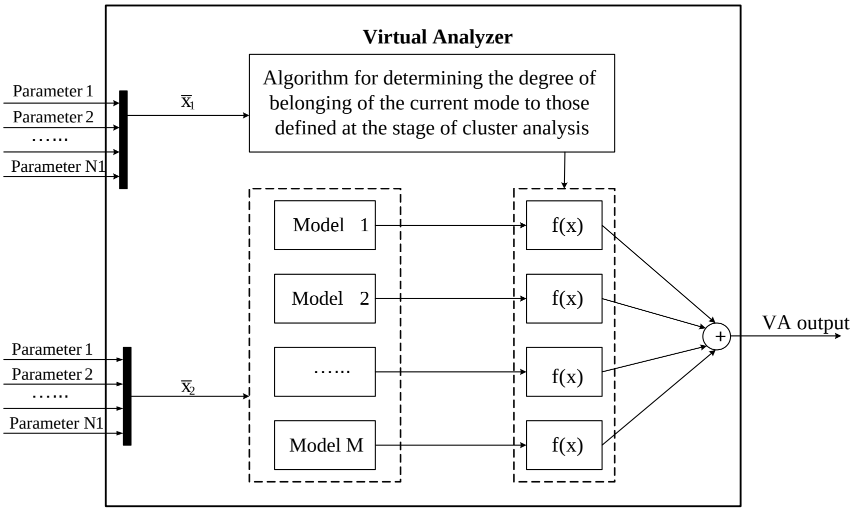


Fig.3. ***Structure of the virtual analyzer.***

The output signal of the virtual analyzer depends on several input signals, not just one input signal. The control object consists of interacting input and output signals. To identify such analyzers, as a rule, a regression analysis method with an active experiment based on the theory of mathematical planning of the experiment is used. The use of this theory significantly reduces the number of test experiments and simplifies the calculations necessary to obtain the regression equation of the output signal with multiple input signals[14].

In the theory of mathematical experiment planning, a reduction in the number of necessary experiments is achieved by simultaneously measuring some input signals. This simplification of calculations is carried out in exchange for normalization of input signals: $\pm\Delta x_{input} = \pm 1$. For example, $x_{Output} = f\left(\Delta x_{1Input}; \Delta x_{2Input}\right)$ - depends on two input factors.

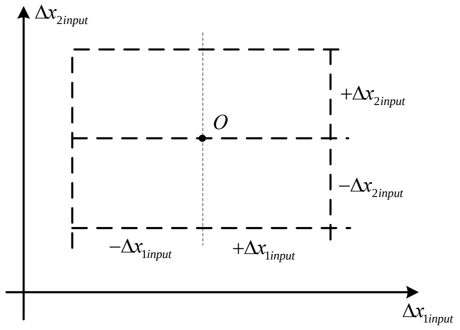


Fig.4. ***The scheme of the study of an object with two input parameters (factors) by the regression analysis method.***

Point O is the nominal operating mode of the object. Normalization is carried out by moving the coordinate system to point O.

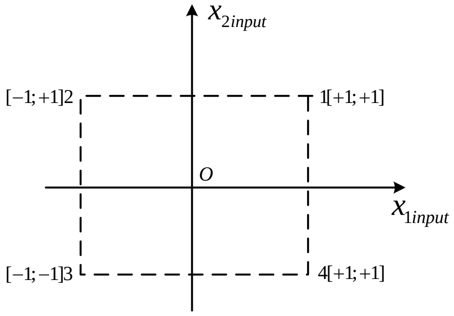


Fig.5. ***The scheme of the central plan for the two input signals of the full factor experiment.***

At the same time (Fig.5) $x_{Output} = f\left(\Delta x_{1Input}; \Delta x_{2Input}\right)$ describes a plan for conducting experiments to study dependence. The number of experiments of the full factorial experiment is $4=2^2$; if the number of input parameters is k, then the number of experiments for the factorial experiment will be $N=2^K$, and for k=3 N=8; for k=4 N=16, etc.

Figure 5 shows a plan for an orthogonal complete factorial experiment with two input factors.

Table 1.

Complete factorial experiment at k=2.

№ Number of experiments	x_{1inp}	x_{2inp}	x_{out}
1	+1	+1	x^{1}_{out}
2	-1	+1	x^{2}_{out}
3	-1	-1	x^{3}_{out}
4	+1	-1	x^{4}_{out}

The orthogonality of the plan is its feature

Table 2.

Complete factorial experiment at k=3.

№ number of experiments	x_{1inp}	x_{2inp}	x_{3inp}	x_{output}
1	+1	+1	+1	x^1_{out}
2	-1	+1	+1	x^2_{out}
3	-1	-1	+1	x^3_{out}
4	+1	-1	+1	x^4_{out}
5	+1	+1	-1	x^5_{out}
6	-1	+1	-1	x^6_{out}
7	-1	-1	-1	x^7_{out}
8	+1	-1	-1	x^8_{out}

In the full factor plan of experiments, the number of experiments increases depending on the number of input factors of the experiment: k=4, N=16; k=5, N=32; k=6, N=64. Therefore, in order to reduce the number of experiments with small information losses, plans with a short decimal response are used. If the plan consists of half of a complete factorial experiment, then such a plan is called a half copies.

Table 3.

Example of a half copy at k=4 (TFE=16)

№ number of experiments	x_{1inp}	x_{2inp}	x_{3inp}	x_{4inp}
1	+1	+1	+1	+1
2	+1	-1	+1	-1
3	-1	+1	+1	-1
4	-1	-1	+1	+1
5	+1	+1	-1	-1
6	+1	-1	-1	+1
7	-1	+1	-1	+1
8	-1	-1	-1	-1

One-factor experiments also use replicas of $\frac{1}{4}$.

The equations of the relationship between the input and output signals (i.e. regression equations) are written in the form of an algebraic polynomial of the first, second order :

A polynomial of degree 1

$$x_{output} = b_0 + b_1 x_1 + b_2 x_2 \tag{1}$$

taking into account the influence of the input factor X_1 on the second input factor X_2:

$$x_{output} = b_0 + b_1 x_1 + b_2 x_2 + b_{12} x_1 x_2 \tag{2}$$

The complete regression equation of the second order:

$$x_{output} = b_0 + b_1 x_1 + b_2 x_2 + b_{12} x_1 x_2 + b_{11} x_1^2 + b_{22} x_2^2 \tag{3}$$

Naturally, this equation more accurately expresses the relationship between the output and the input signals. The issue of identifying the control object by regression analysis is solved by choosing the order of the mathematical model and determining the coefficients b_0, b_1, b_2, b_{12} and others in this equation.

When determining the coefficients, the least squares method is used, according to which the deviations between the real value and the calculated value are calculated by the smallest sum of quadratures. In other words, he is looking for the minimum of the function

$$\Phi = \sum_{i=1}^{n} (x_{iout}^{eks} - x_{iout}^{regr})^2 \to \min \tag{4}$$

When the first derivative is zero, the function Φ reaches a minimum.

$$\frac{\partial \Phi}{\partial b_0}; \frac{\partial \Phi}{\partial b_1}; \frac{\partial \Phi}{\partial b_2}; \frac{\partial \Phi}{\partial b_{12}} = 0 \tag{5}$$

For example, when using the least squares method, there is:

$$\sum_{i=1}^{n} (x_{iout}^{eks} - x_{iout}^{regr})^2 \to \min \tag{6}$$

Let the output signal depend on only one input factor. N experiments were conducted, $\sum_{i=1}^{n} x_{iinp}^{eks}$ and $\sum_{i=1}^{n} x_{iout}^{eks}$ experimental results were obtained:

The general form of the regression equation of the 1st order is as follows:

$$X_{output} = b_0 + b_1 x_1 \tag{7}$$

We are looking for the minimum of the function Φ by the least squares method:

$$\Phi = \sum_{i=1}^{n} (x_{iout}^{eks} - x_{iout}^{regr})^2 = \sum_{i=1}^{n} (x_{iout}^{eks} - b_0 - b_1 x_{iinput})^2 \tag{8}$$

To find the minimum of this function, we equate a specific derivative to zero.

$$\frac{\partial \Phi}{\partial b_0} = 0; \frac{\partial \Phi}{\partial b_1} = 0$$

To make it convenient to get a specific derivative, we insert the variable $x_0=1$ into the equation, and it takes the following form:

$$\Phi = \sum_{i=1}^{n} (x_{iout}^{eks} - \mathrm{b}_0 x_0 - \mathrm{b}_1 \mathrm{x}_{iinput})^2, \tag{9}$$

$$\begin{cases} \dfrac{\partial \Phi}{\partial b_0} = 2\sum\limits_{i=1}^{n} (x_{iout}^{eks} - \mathrm{b}_0 x_0 - \mathrm{b}_1 \mathrm{x}_{iinput})^2 \cdot x_0 = 0 \\ \dfrac{\partial \Phi}{\partial b_1} = 2\sum\limits_{i=1}^{n} (x_{iout}^{eks} - \mathrm{b}_0 x_0 - \mathrm{b}_1 \mathrm{x}_{iinput})^2 \cdot \mathrm{x}_{iinput} = 0 \end{cases} \tag{10}$$

Now $x_0=1$ can be deleted.

$$\begin{cases} b_0 \cdot n + \sum\limits_{i=1}^{n} \mathrm{b}_1 \mathrm{x}_{\mathrm{iinput}} = \sum\limits_{i=1}^{n} x_{iout}^{eks} \\ b_0 \cdot \sum\limits_{i=1}^{n} \mathrm{x}_{\mathrm{iinput}} + b_1 \cdot \sum\limits_{i=1}^{n} \mathrm{x}_{\mathrm{iinput}}^2 = \sum\limits_{i=1}^{n} x_{iout}^{eks} \cdot \mathrm{x}_{\mathrm{iinput}} \end{cases} \tag{11}$$

Solving this system (by Kramer's method) we find:

$$b_0 = \frac{\sum\limits_{i=1}^{n} x_{iout}^{eks} \cdot \sum\limits_{i=1}^{n} \mathrm{x}_{\mathrm{iinput}}^2 - \sum\limits_{i=1}^{n} x_{iout}^{eks} \cdot x_{iinput} \cdot \sum\limits_{i=1}^{n} x_{iinput}}{n \cdot \sum\limits_{i=1}^{n} x_{iinput}^2 - (\sum\limits_{i=1}^{n} x_{iinput})^2} \tag{12}$$

$$b_1 = \frac{n \cdot \sum\limits_{i=1}^{n} x_{iout}^{eks} \cdot x_{\mathrm{iinput}} - \sum\limits_{i=1}^{n} x_{\mathrm{iinput}} \cdot \sum\limits_{i=1}^{n} x_{iout}^{eks}}{n \cdot \sum\limits_{i=1}^{n} x_{iinput}^2 - (\sum\limits_{i=1}^{n} x_{\mathrm{iinput}})^2} \tag{13}$$

To check the accuracy of the mathematical model, the regression equation of the observed object is checked according to several adequacy criteria. From the very beginning, the results of the experiment cannot be clearly formulated, since the results and their analysis are associated with uncertainties and probabilities. The probability will vary within the limits that there will be no event 0, and event 1 will definitely be. In a large number of parallel experiments (homogeneous conditions), the probability can be given in the form of a distributed probability function (Fig. 6.).

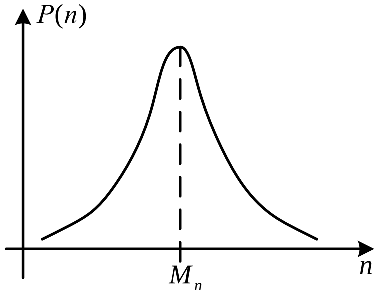


Fig.6. ***Scheme of the normal law of probability distribution.***

A random variable (x^{i}_{output}) has a number of characteristics, the most important of which are expectation and variance. Mathematical expectation is the average mixed value of a random variable[16].

$$M_{xoutput} = \sum_{i=1}^{n} x_{iout} \cdot p(x_{iout}) \tag{14}$$

The variance expresses the scattering relative to the mathematical expectation of a random variable.

$$D(x_{iout}) = M[x_{iout} - M(x_{out})]^2 = \sum_{i=1}^{n} [x_{iout} - M_{x_{out}}]^2 \cdot p(x_{iout}) \tag{15}$$

The adequacy of the regression equation is checked on the basis of the Fisher criterion or the Student's F-criterion:

Equation $x^{regr}_{out} = b_0 + b_1 x_{1input}$ ends by determining how different it is from equation $x^{regr}_{output} = x^{sr}_{output}$. To do this, the relative variance of the average value of the output signal is calculated.

$$S^2_{average} = D_{average} = \frac{\sum_{i=1}^{n} (x^{eks}_{iout} - x^{aver}_{out})^2}{n-1 = f_1} \tag{16}$$

where f_1 is the number of degrees of freedom, f_2 is the number of degrees of freedom.

$$x^{aver}_{out} = \frac{\sum_{i=1}^{n} x^{eks}_{iout}}{n-1 = f_1} \tag{17}$$

The value of the Fisher criterion is determined by the following equation:

$$F = \frac{D_{aver}}{D_{ast}} > F_{tabl} \tag{18}$$

The importance of the bi coefficients in the regression equation is determined using the t–criterion (Student's criterion).

$$t = \frac{|b_i|}{\sqrt{D_{b_i}}} > t_{table} \tag{19}$$

$$D_{b_i} = \frac{D_{ast} \cdot n}{n \cdot \sum_{i=1}^{n} x^2_{iinput} - (\sum_{i=1}^{n} \mathrm{x}_{\mathrm{iinput}})^2} \tag{20}$$

Figure 7 shows the results of comparing the results of modeling an object by a third-order polynomial equation with the results of physical modeling of a real process.

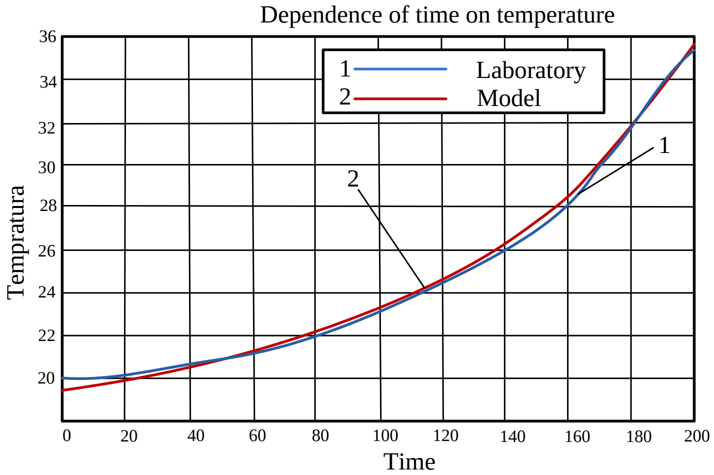


Fig.7. ***A third-order polynomial equation and a graph of experimental results.***

As can be seen from the graph, a mathematical model in the form of a third-order polynomial equation can be used as a process model.

Conclusion

Operational dispatch quality management of final products, in industrial, real–world conditions, is carried out through monitoring and evaluation of production situations. This monitoring is carried out by collecting, storing and processing information received from sensors and laboratory analyses.

Currently, three methods of control prevail to assess the quality of products obtained at the enterprises of the production of mineral fertilizers: 1) laboratory analyses, 2) in-line data, as well as data obtained using virtual analyzers. However, industrial laboratories are not always able to provide the necessary completeness and efficiency of measurement information, and therefore, the results of laboratory analyses cannot be applied in real-time quality management.

In-line analyzers need constant calibration, which is expensive and for this reason analyzers are not always available. In contrast, virtual analyzers are almost as accurate as instrumental analyzers inaccuracy, and at the same time much cheaper and more reliable. The principle of operation of virtual analyzers is based on the continuous determination of the quality indicator by a mathematical model describing its relationship with the current values of the measured technological parameters. Virtual analyzers of the quality of final products for such measured parameters of the technological process as temperature, pressure, flow, allow continuous monitoring and optimal control of heat and mass transfer. Processes of production of mineral fertilizers.

It should be noted that the disruption of the functioning of such technological facilities for responsible purposes, such as a drum drying industrial installation, can lead to environmentally serious consequences. Therefore, these technological facilities are in urgent need of continuous monitoring of the quality of the final products. The improvement of VA models is an urgent task, the solution of which leads to an increase in the efficiency of the functioning of responsible facilities.

Reference:

1. Yusupbekov, N.R., Igamberdiev, H.Z., Mamirov, U.F. (2020). Adaptive control system with a multilayer neural network under parametric uncertainty condition. *International Conference on Intelligent and Fuzzy Systems INFUS 2020: Intelligent and Fuzzy Methods: Smart and Innovative Solutions CEUR Workshop Proceedings*, 2782, 228-2341.
2. Zakharenko, V.A. (2000). World trends in the production and use of mineral fertilizers. *Agrochemistry*, 5.
3. Rylov, M.A., Sofiev, A.E. (2012). Building a product quality model based on the data of the unified information space of the enterprise. *Devices*, 10, 23-29.
4. Samoylova, S.A., Torgashov, A.Yu. (2019). Construction of a virtual analyzer of the rectification process in conditions of a small training sample of data. *Mathematical methods in engineering and technologies-MMTT*, 2, 10-13.

5. Guryeva, E.M., Ibatullin, A.A. (2016). Quality virtual analyzers in oil refining. *Auto repair, mechatronics, information technologies -2016: materials of the VI International. sci.- tech*. Omsk: Omskiygos. tech. un-t, 181-186.
6. Wang, D., Murphy, M. (2004). Estimating optimal transformations for multiple regression using the ACE algorithm. *Journal of Data Science*, 2, 329-346.
7. Bachtadze, N., Lototsky, V., Maximov, E., Pavlov, B (2007). Associative Search models in Industrial systems. *IFAC International Workshops Intelligent Assembly and Disassembly (IAD'02)& Intelligent Manufactoring Systems (IMS'07)-Alicamte*, Spain, 1.2007.
8. Konovalov, Yu.V. (2013). *Statistical modeling using regression analysis: method. Computer and statistical modeling*. Moscow: Bauman Moscow State Technical University.
9. Kochengin, A.E., Leonov, A.V., Barbasova, T.A. (2015). Application of clustering methods for determining the operating modes of a blast furnace. *New word in science: prospects for development: materials of the VI Inter-nar. scientific–practical. conf.* Cheboksary, 152-153.
10. Labinsky, A.Yu. (2018). The use of fuzzy logic in solving classification problems. *Bulletin of the St. Petersburg University of the State Fire Service of the Ministry of Emergency Situations of Russia*, 3.
11. Dozortsev, M., Itskovich, E.L., Kneller, D.V. (2013). Improved process control (APC): 10 years in Russia. *Automation in industry*, 1. 12-19.
12. Ershov, K.S., Romanova, T.N. (2016). Analysis and classification of clustering algorithms. *New information technologies in automated systems*, 19, 274-279.
13. Ivanchenko, A.V., Melnikov, A.V. (2013). Stages of clustering in data mining. *Prospects for the development of information technologies*, 12, 17-22.
14. Larichev, O.I., Moshkovich, E.M. (1996). *Qualitative methods of decision-making*. Moscow: Fizmatlit.
15. Alpatov, B., Babayan, P. (2010). Extraction of the objects observed on a non-uniform background during sensor motion. Electro-Optical Remote Sensing, Photonic Technologies and Applications IV, edited by Gary W. Kamerman, Ove Steinvall, Keith L. Lewis, Richard C. Hollins, Thomas J. Merlet, proc. of SPIE, 7835 (SPIE, Bellingham, WA 2010) 78350N.
16. Potocki, V.A., Fadeev, V.M., Maksimov, E.A., Bakhtadze, N.N. (2004). Virtual analyzers of the quality of technological process control based on a nonlinear dynamic predictor. *Abstracts of the 5th International dokpads. Conferences "Problems of management and energy"*.Tbilisi, Georgia, 35 p.