Application of Sensors in Real Time Systems for Optimizing Industrial Processes in Chemical Facilities

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***Abstract*: An overview of automated industrial plant and its architecture has been discussed briefly in this paper. The content herein is very educative at introductory stage to concept of Industrial Automation and Informative about latest trends in Industrial Automation. Mineral processing and Chemical producers are building new plants need technologies that help them get the most from their assets, while also helping them minimize safety and quality risks. The ability to accurately measure valuable elements and minerals is critical for optimizing processes. Our emerging sensor technologies provide real-time results, opening up opportunities to make significant cost savings and increase mineral recovery rates.**

I. INTRODUCTION

Today we can witness many examples of mechanization in the most diverse areas of human activity. In the agricultural sector, the application of the means of mechanization (tractors with trailers, combines, etc.) is the most direct replacement of human energy with other types of energy. In the mechanical industry, there are tools for mechanization of the various craft works (pneumatic and electrical devices for carrying out various locksmithing works), which have facilitated the work of the worker and increased the productivity and quality of the work. In everyday, domestic work, the most widely used means for mechanization, picking up from the tools for processing wood and metals (various electric chains, asses, etc.), and all the way to the asset for working in the kitchen (electric mixers, machines for melting, etc.). In the modern conditions of living in the reproduction processes, the mechanization of the transfer of various goods occupies a significant place, both in the production facilities itself, as well as in the loading, unloading or loading of goods in transport vehicles and landfills (transport lanes, elevators, villa sharks).

Jointly for all the above-mentioned means of mechanization, they need direct participation of the people in their management, in the execution of the foreseen technological process.

Improvements to the machinery for mechanization, as well as the ever increasing demands for increased productivity and quality, have further increased the process of managing the machines. This imposed the need for the liberation of the man and the function of the manager of the means of mechanization, and the term automation, which characterizes the stage of the liberation of the man and the management of the operation of mechanisms and machines, came to mind. The essential difference between automation and mechanization is precisely in the machinery of management. Mechanization is an inevitable prerequisite for automation, as the utilization of natural energy is a prerequisite for mechanization.

The automation of our wide application in all areas of human activity. This apartment is a symbol of modern life. In the most diverse industrial branches (the mechanical, wood, food, graphic, processing, etc.), the automatic machines and lines are widespread, and the automation is also represented in the traffic (traffic regulation, automatic management of transport means), links (automatic telephone exchanges), administration, etc. activities.

II. AUTOMATION AND AUTOMATIZATION OF PROCESSES

Automation is closely related to the concept of automation. When we talk about the automation today, we think about modern machines, modern universal ships, computers and robots. In addition, we do not think that the principles and laws on which the automation is based are inherent in nature. History can be followed by the development of the various tools and devices they need for the people in their entire activity. The first man-made techniques were simple tools, work tools and weapons. Later, he invented everything that he had ever done, but in time again, he managed to imagine them creating such activities that he would perform them without his action. It is the beginning of the development of the area that we now call automation.

The automaton is a scientific-technical field, the subject of which is the study of the theory and the techniques of automatic control, and it also includes:

- investigation of the conditions and laws according to the different formations;
- investigate the conditions and laws according to which the automatic systems in which automatic control is provided;
- research, design and construction of technical means;
- analysis, synthesis (design) and construction of automated control systems. Also, you need to split yourself into automation. Automation is a branch of science and techniques that encompass information theory, the theory of automatic management of methods for processing and use of information (algorithms), the theory of connections and the principles of the management processes.

III. SENSORS, SIGNALS, AND SYSTEMS

A sensor is often defined as a “device that receives and responds to a signal or stimulus.” This definition is broad. In fact, it is so broad that it covers almost everything from a human eye to a trigger in a pistol. The operator adjusts the level of fluid in the tank by manipulating its valve. Variations in the inlet flow rate, temperature changes (these would alter the fluid’s viscosity and consequently the flow rate through the valve), and similar disturbances must be compensated for by the operator. Without control, the tank is likely to flood, or run dry. To act appropriately, the operator must obtain timely information about the level of fluid in the tank. In this example, the information is generated by the sensor, which consists of two main parts: the sight tube on the tank and the operator’s eye, which produces an electric response in the optic nerve. The sight tube by itself is not a sensor, and in this particular control system, the eye is not a sensor either. Only the combination of these two components makes a narrow-purpose sensor (detector), which is selectively sensitive to the fluid level. If a sight tube is designed properly, it will very quickly reflect variations in the level, and it is said that the sensor has a fast speed response. If the internal diameter of the tube is too small for a given fluid viscosity, the level in the tube may lag behind the level in the tank. Then, we have to consider a phase characteristic of such a sensor.

In some cases, the lag may be quite acceptable, while in other cases, a better sight tube design would be required. Hence, the sensor’s performance must be assessed only as part of a data acquisition system.

The purpose of a sensor is to respond to some kind of an input physical property (stimulus) and to convert it into an electrical signal that is compatible with electronic circuits. We may say that a sensor is a translator of a generally nonelectrical value into an electrical value. When we say “electrical,” we mean a signal, which can be channeled, amplified, and modified by electronic devices. The sensor’s output signal may be in the form of voltage, current, or charge. These may be further described in terms of amplitude, polarity, frequency, phase, or digital code. This set of characteristics is called the output signal format. Therefore, a sensor has input properties (of any kind) and electrical output properties.

The term sensor should be distinguished from transducer. The latter is a converter of any one type of energy into another, whereas the former converts any type of energy into electrical energy. Transducers may be used as actuators in various systems. An actuator may be described as an opposite to a sensor; it converts electrical signal into generally nonelectrical energy. For example, an electric motor is an actuator; it converts electric energy into mechanical action. Another example is a pneumatic actuator that is enabled by an electric signal.

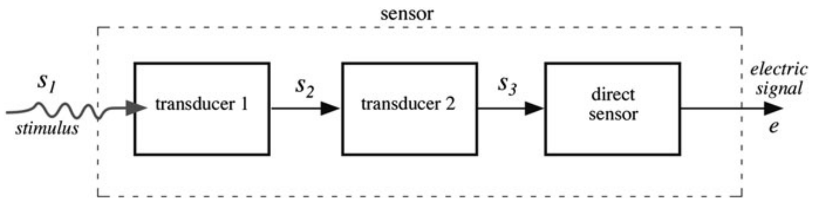

Figure 1. A sensor may incorporate several transducers. s_1, s_2, and so on are various types of energy.

IV. TRANSFER FUNCTION

An ideal or theoretical input–output (stimulus–response) relationship exists for every sensor. If a sensor is ideally designed and fabricated with ideal materials by ideal workers working in an ideal environment using ideal tools, the output of such a sensor would always represent the true value of the stimulus. This ideal input–output relationship may be expressed in the form of a table of values, a graph, a mathematical formula, or as a solution of a mathematical equation. If the input–output function is time invariant, it is commonly called transfer function.

The transfer function represents the relation between stimulus s and response electrical signal S produced by the sensor. This relation can be written as S 1⁄4 f(s).

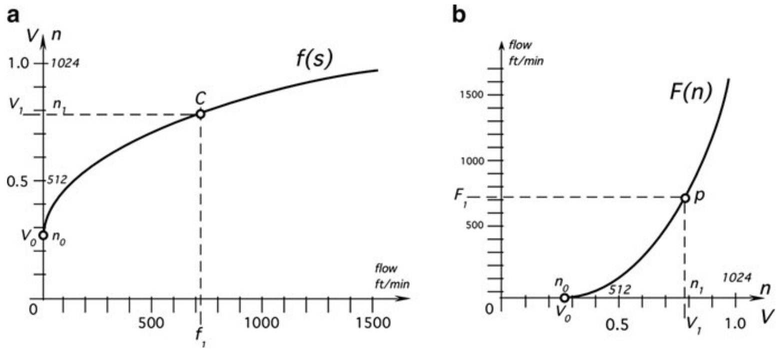

Figure 2. Transfer function (a) and inverse transfer function (b) of a thermo-anemometer

Normally, stimulus s is unknown while the output signal S is measured. An inverse f^{-1}(S) of the transfer function is required to compute the stimulus from the sensor's response S.

V. MATHEMATICAL MODEL

Preferably, a physical or chemical law that forms a basis for the sensor's operation should be known. If such a law can be expressed in form of a mathematical formula or model, often it can use to calculate the sensor's inversed transfer function by inverting the formula and computing the unknown value of s from the measured S. For example, if a linear resistive potentiometer is used for sensing displacement d, an Ohm's law can be applied to compute the transfer function. In this case, the response S is the measured voltage v and the inverse transfer function F(S) can be given as

$$d = \frac{v}{E} D,$$

where E is the reference voltage and D is the maximum displacement (full scale); both are constants. From this function we can compute displacement d from the measured voltage v. In practice, readily solvable formulas for many transfer functions, especially for complex sensors, do not exist and one has to resort to various approximations of the direct and inverse transfer functions.

VI. CHEMICAL SENSORS

In industry, chemical sensors are used for process and quality control during plastics manufacturing and in the production of foundry metals where the amount of diffused gasses affects metal characteristics such as brittleness. They are used for environmental monitoring of workers to control their exposure to dangers and limit health risks. Chemical sensors find many new applications as electronic noses. An electronic nose generally uses different types of sensor technologies in order to mimic the olfaction capabilities of mammals. In medicine, chemical sensors are used to determine patient health by monitoring oxygen and trace gas content in the lungs and in blood samples. These sensors are often used for breathalyzers to test for blood alcohol levels and as indicators of the digestion problems of patients. In the military, chemical sensors are used to detect fuel dumps and to warn soldiers of the presence of airborne chemical warfare agents. Chemical sensors are used to detect trace contaminants in liquids, and, for example, they are used to search for and monitor ground water contamination near military, civilian, and industrial sites, where significant amounts of chemicals are stored, used, or dumped. Combinations of liquid and gas sensors are used in experimental military applications to monitor compounds produced from refineries and nuclear plants to verify compliance with weapons treaties.

VII. APPLICATION OF SENSORS IN INDUSTRIAL PROCESSES WITH THE EVOP (EVOLUTIONARY OPERATION) METHOD

Modern industrialization and the breakthrough of modern industrial processes comes as a result of implementation and utilization of information technology, advances in programming and software engineering, and all available tools that support the optimization and automation of all processes. Applied computer programs for calculation of technological indicators in mineral technology, economic and technical efficiency – show modest results in the process of optimization of all processes.

The need for optimization comes from the aspect of business and economic trends, management, industrial and other processes. The need for continuous improvement is a key aspect in management; whether there is a need for increase in production of raw materials, or increasing profits when investing in particular endeavor. Since there is only one answer to the problem, we need to choose the "best" solution (or more possible solutions to the problem). So, first the purpose of the problem has to be determined: is it ***economic*** or ***technical.***

Economic purposes can include: maximizing profit, minimizing costs etc. Technical purposes can include the following: higher annual production, minimal losses during the operation of a certain machine, greater productivity etc. It's understandable that in industrial optimization prevails the economic form of the goal. If the goal isn't previously determined, an improvement cannot be executed, because there is no basis for comparison of multiple solutions. The problem must be defined so that all its information can be in a quantitative form, and that is the ***function of the goal***, which is used to select decisions in the system's **changeables**.

Information on most cycles in the real environment, as well as in mineral technology, such as technological, i.e. the size of parameters in models from processing units in the cycle - require information on input or output parameters in the closed cycle. The size of the remaining parameters are calculated or derived from other measured characteristics. The full calculation of the data actually is far more complex and requires full study of the techniques that can be applied, including their advantages or disadvantages, which would be a subject of further study or elaboration.

Systems engineering can be defined as a conception, planning, designing and engineering of influential elements of each system which still exists in the moment of processing. System analyzes represent a scientific method for bringing decisions which are based on quantitative and other objective evaluations of all alternatives that exist in systems and which are upgraded during their processing. Operational research is defined as an application of mathematical models in the problem of optimization of the goal of every system that is previously defined. These three disciplines are very similar in their aims, but only operational research by nature and form are more mathematical, hence an important and often obligatory part of the other two disciplines.
For this purpose, an attempt is made in this paper is to add to the existing real time processes a sensor to appropriate segment of the industrial process to minimize the cost and not necessary over usage of chemical substances or reagents.

EVOP (evolutionary operation) is a method for optimizing industrial or technological processes during production. The EVOP method represents a simplification of the procedure of a two-factorial and three-factorial experiment. This method uses operational data from the production process in order to improve the conditions for the operation of the process, so as to achieve continuous improvement of the function's function of the target in relation to the previously achieved. During the work two or three independent variables are considered (influential factors). With the assistance of ESOP, the effects of independent variables (influencing factors) and their interactions can be analyzed, with the task of providing data to the operator in order to systematically advance the production process in progress, i.e. to directly act and manage the production. With this method, the achievement of the goal is accelerated several times, and it is not necessary to stop the normal production or stop the process. The method is based on statistical concepts and it is possible to monitor the risk of error. The ESOP will rely on the concept: to accelerate the evolution of the natural process (technological) if changes are made, and then they are selected so as to lead to an optimal solution. These changes in the industrial process are, in fact, the different production conditions (values of the influential factors), but so limited that such changes cannot be achieved, for the market, unacceptable products or effects within unacceptable limits. The impact of those changes on the response surface, i.e. of the analyzed dependent variable is measured and compared with the limits of border error confidence, calculated on the basis of the data. Based on this, it can be assessed whether the induced changes (of factors) have produced visible effects. If it is shown that the new conditions have an advantage, the chance that appears in the set of the then-realized data (conditions), then passes to a new state, i.e. new values of influential factors (standards). Developing the EVOP procedure at a certain point (conditions) as the center of a new state, this moves the position of the conditions from one center to another, and this shift represents a shift to the optimal solution (optimal operating conditions).

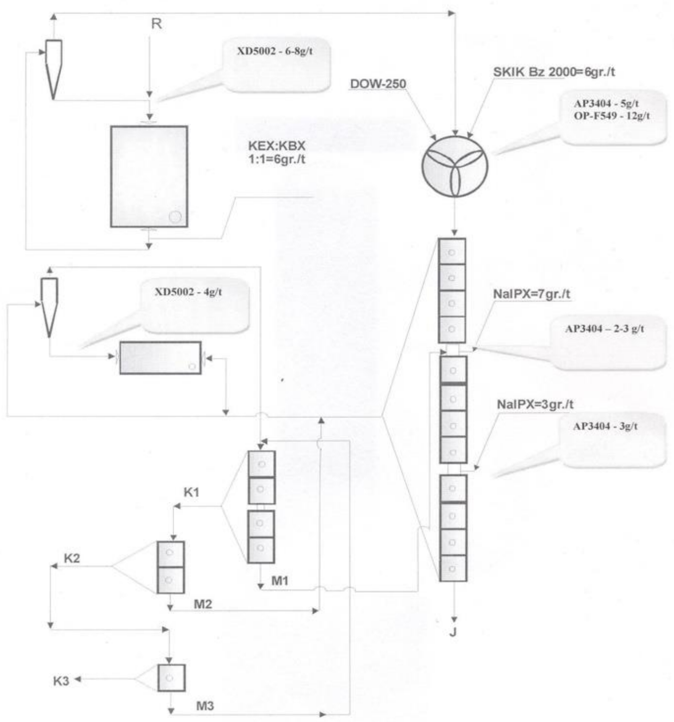

Figure 3. Reagent mode flotation in mine “X”

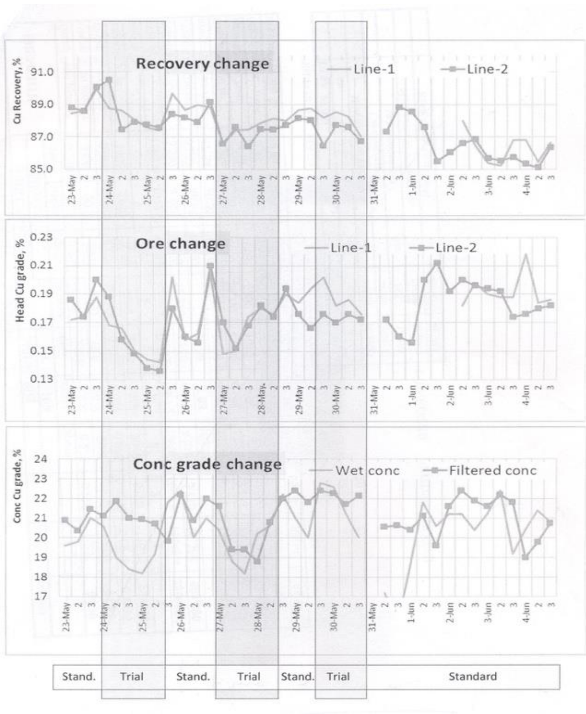

Figure 4. Obtained results in real terms

A. *Laboratory tests for copper and gold (Cu / Au) in "X" mine with experimental plan*

During the period of two years in the flotation of the mine "X", investigations were carried out with the change of the reagent regime, the fermentation of the ore and other parameters, which influence the utilization and quality of copper and gold in the concentrate. By adding chemical sensors to key segments of the industrial / chemical process itself we can change or even get better results on required mineral.

Table 1. Standard conditions for flotation in "X" mine

Experiment	Collectors, type	Collectors, gr/t	pH	Frothers, type	Frothers, gr/t
T – 1	BZ+KEX+KBX+NaIPX	22	11.8	DowF	20
T - 2	BZ+KEX+KBX+NaIPX	22	11.8	OP 549	20

Table 2. Investigated conditions for flotation - plan experiments (DOE)

Experiment	Collectors, type	Collectors, gr/t	pH	Frothers, type	Frothers, gr/t
T – 1	BZ+KEX+KBX+NaIPX	22	11.8	DowF	20
T - 2	BZ+KEX+KBX+NaIPX	22	11.8	OP 549	20
R-1	Aero MX-950	16	10.5		
R-2	AP-3418A	16	9.5		
R-3	Aero MX-5127	16	10.5		
R-4	AP-3418A	16	10.5		
R-5	5002	22	9.5		
R-6	5002	16	10.5		
R-7	AP-3418A	22	10.5		
R-8	Aero MX-950	22	9.5		
R-9	3404	16	9.5		
R-10	AP-3418A	22	9.5		
R-11	Aero MX-950	22	10.5	OP 549	20
R-12	Aero MX-5127	22	9.5		
R-13	3404	22	10.5		
R-14	5002	16	9.5		
R-15	5002	22	10.5		
R-16	Aero MX-5127	16	10.5		
R-17	Aero MX-950	16	9.5		
R-18	3404	16	9.5		
R-19	3404	22	10.5		
R-20	Aero MX-5127	22	9.5		
R-21(R-17)'	Aero MX-950	16	9.5		
R-22(R-11)'	Aero MX-950	22	10.5		
R-23(R-7)'	AP-3418A	22	10.5		

Table 3. Tests with a plan experiments on copper

Experiment	Quality, Cu%			Utilizing, Cu%	
	r	k	j	K	J
T – 1	0.29	2.3	0.053	83.4	16.6
T - 2	0.31	2.8	0.050	85.6	14.4
R-1	0.28	2.4	0.038	87.9	13.1
R-2	0.29	2.5	0.031	90.5	9.5
R-3	0.27	2.4	0.049	83.7	16.3
R-4	0.32	3.0	0.034	90.5	9.5
R-5	0.26	2.4	0.034	88.5	11.5
R-6	0.31	2.7	0.044	87.3	12.7
R-7	0.29	3.2	0.036	88.8	11.2
R-8	0.30	3.0	0.035	89.4	10.6
R-9	0.30	3.2	0.045	86.5	13.5
R-10	0.27	1.7	0.035	89.1	10.9
R-11	0.27	2.3	0.028	90.7	9.3
R-12	0.25	2.8	0.031	88.5	11.5
R-13	0.27	3.6	0.031	89.4	10.6
R-14	0.27	3.0	0.028	90.5	9.5
R-15	0.26	2.2	0.025	91.6	8.4
R-16	0.25	2.1	0.031	89.2	10.8
R-17	0.27	3.0	0.030	89.8	10.2
R-18	0.27	2.6	0.029	90.1	9.9
R-19	0.26	3.0	0.027	90.4	9.6
R-20	0.24	1.9	0.028	89.5	10.5
R-21(R-17)'	0.25	3.1	0.027	90.2	9.8
R-22(R-11)'	0.25	2.2	0.029	89.8	10.2
R-23(R-7)'	0.25	2.9	0.024	91.1	8.9

R-1 ÷ R-23 researches show that newly offered collectors at reduced pH values show satisfactory results for copper and gold separation (Table 1 and Table 2) and are relatively higher than the industrial results obtained for 2010 (Table 3). However, the required tests under different conditions performed under adequate conditions, somewhat confirm the industrial results in 2011/2012.

B. Optimizing the reagent regime in the phase of copper flotation in the mine "X"

On the basis of experiments carried out in laboratory and industrial conditions in copper flotation at mine “X”, it came to the conclusion that future investigations should go in the direction of optimization with optimization methods that will optimize the reagent regime. Therefore, based on the industrial - laboratory null values of the collectors in the photovoltaic stages, analysis was carried out using the optimization technique.

Initial values of collectors in phases of flotation:
X1 - collector consumption NaIPX = 12 gr / t
X2 - collector consumption KBX: KEX = 1: 1 = 8 gr / t
X3 - collector consumption SKIK 2025 = 4 gr / t
Variable values of collectors at different stages of flotation:
ΔX1 - Collector consumption NaIPX ± 3 gr / t
ΔX2 - Collector consumption KBX: KEX = 1: 1 ± 2 gr / t
ΔX3 - Collector consumption SKIK 2025 ± 1 gr / t

Table 4. Tests with a plan experiments – “X” Mine

Experiment	X_0	X_1	X_2	X_3	I_1	I_2	$I_{Cu}\%_{av}$
1	+	15	10	5	90,13	89,05	89.59
2	+	15	6	5	90,52	87,90	89.21
3	+	9	10	5	89,18	88,80	88.99
4	+	9	6	5	86,66	87,22	86.94
5	+	15	10	3	89,10	87,22	88.16
6	+	15	6	3	88,60	90,48	89.54
7	+	9	10	3	88,90	89,62	89.26
8	+	9	6	3	88,00	87,08	87.54

Other operating parameters (pH = 11.72, 55-60% - 0.074 mm, flotation time (12 min) and conditioning (6 min)) standards as in industrial conditions. Two parallel investigations were carried out.
The coefficients of the linear model for the values for using the copper in concentrate $I_{Cu}\%_{av}$ are:
b0 = 1 / n [89.59 + 89.21 + 88.99 + 86.94 + 88.16 + 89.54 + 89.26 + 87.54] = 88.65
b1 = 1 / n [89.59-89.21 + 88.99-86.94 + 88.16-89.54 + 89.26-87.54] = 0.346
b2 = 1 / n [89.59 + 89.21-88.99-86.94 + 88.16 + 89.54-89.26-87.54] = 0.47
b3 = 1 / n [89.59 + 89.21 + 88.99 + 86.94-88.16-89.54-89.26-87.54] = 0.03
b12 = 1 / n [89.59-89.21-88.99 + 86.94 + 88.16-89.54-89.26 + 87.54] = - 0.596
b13 = 1 / n [89.59-89.21 + 88.99-86.94-88.16 + 89.54-89.26 + 87.54] = 0.26

b23 = 1 / n [89.59 + 89.21-88.99-86.94-88.16-89.54 + 89.26 + 87.54] = 0.24
b123 = 1 / n [89.59-89.21-88.99 + 86.94-88.16 + 89.54 + 89.26-87.54] = 0.18

C. Research on the linear model with modified reagent mode

Analyzing the linear model of the polynomial of the first order for the utilization of copper from the chalcopyrite ore, investigations were carried out by increasing the independent variable (x1-collector NaIPX) and increasing the independent variable (x2-collector KEX: KBX = 1: 1). The obtained results of the tests are given in Table 5.

Table 5. Tests with a plan experiments

Experiment	X_1	X_2	I_1	I_2	$I_{Cu}\%_{av}$
1	15	10	90.0	89.2	89.6
2	**16**	**11**	**90.4**	**90.0**	**90.2**
3	17	12	90.1	89.3	89.7
4	18	13	89.7	89.3	89.5

Other operating parameters (pH = 11.72, 5560% - 0.074 mm, flotation time (12 min) and conditioning (6 min), X3 = 4 ÷ 6 gr / t) standards as in industrial conditions. Two parallel investigations were performed.

The use of copper in a concentrate ICu% is optimal, or it requires minimal insignificant increase in the consumption of the NaIPX collector = 15-16 gr / t, and an increase in KBX: KEX = 1: 1 = 1011 gr / t, based on the test representative sample, higher content of copper at the entrance, higher consumption of collectors and vice versa.

After determining the linear model and the adequacy, in order to arrive at the optimal values of the variable factors x_1 and x_2, another series of several experiments is performed. In addition, the signs in front of the coefficients of the variable factors b1, b2 show whether the value of the corresponding factors in those trials should increase (sign "+") or decrease (sign "-") proportionally to the size of their coefficients. In this way, the experiments are performed as long as the function Y gets a better value compared to the previous experiment.

VIII. CONCLUSION

In modern industrial practice (mineral technology, inorganic and organic technology, and other processes), more and more often goes to the application of a combination of program packages, software engineering, application of sensors or software development and optimization programming of existing processes in order to enable the first step towards proper optimization, and the possible automation of technological processes. Also, with the implementation and adding of sensors to the process, the process can be improved in its optimization.

Information about most cycles in the real environment or industrial processes requires information about the size or content for the input or output parameters in the closed loop. In most cycles, measurements are performed at the entrance to the process or cycle, that is, at the output of the manufactured products or occasionally on interstitial products. The sizes of the remaining parameters are calculated or derived from other measured characteristics, such as content distribution or sample size collected or taken at appropriate points in the cycle, emission of gases, optimal solvent content, or other. We can improve or make it easy to store od analyze data so the process can be more autonomous with the applying of the sensor on certain spot in the cycle or on specific machine to gather the date from the live cycle. The research of the performance of the cycle by applying mathematical simulation and optimization involves:

• Calculation of the full material balance of the cycle from incomplete data in the plant;

• Calculation of the model parameters from the complete data network in the plant;

• Optimization through the simulation of the personal computer cycle followed by optimizing tools and controlled by chemical sensors;

• Utilizing a personal computer for ready-made, developed or adapted computer programs for calculations, as well as using various software tools.

This technique can be used in automated optimization in almost all processes, where there are control variables and measurable targets, response-variables. Examples can be found in: refining (solvent extraction or ion exchange), pulp processes, various chemical products (paper machines, analytical chemistry, pharmacy), oil refineries and energy production plants, and more.

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