SOI: 1.1/TAS DOI: 10.15863/TAS
International Scientific Journal
Theoretical & Applied Science

p-ISSN: 2308-4944 (print) e-ISSN: 2409-0085 (online)

Year: 2023 Issue: 05 Volume: 121

Published: 30.05.2023 http://T-Science.org

Issue Article

Azim Jurakulovich Khalilov
Navoi State Mining and Technological University
Scientific researcher,
Department of of Higher Mathematics and Information Technology,
Navoi, Republic of Uzbekistan
azim_xj@mail.ru

MODELING AND DEVELOPMENT OF AN ADVANCED CONTROL SYSTEM OF THE PROCESS OF AMMONIA SYNTHESIS

Abstract: *Recently a lot of attention is being given to the decision of research problems and constructions of parametric control systems by uncertain objects. The main objective of the proposed work is to form the development of methods and algorithms that allow to formulate and effectively solve the problems of constructing models and synthesizing control systems for technological processes in conditions of parametric uncertainty and their application in the construction of control systems for specific technological processes. The article deals with the problems of modeling and development of a system for improved control of technological processes of ammonia synthesis in conditions of parametric uncertainty. These developments allow solving various problems of system analysis, optimization and management, making it possible to reach a new level of control of technological production processes.*

Key words: *Uncertainty, computer model, modeling programs, mathematical model, advanced control systems, modernization, ammonia synthesis.*

Language: *English*

Citation: Khalilov, A. J. (2023). Modeling and development of an advanced control system of the process of ammonia synthesis. *ISJ Theoretical & Applied Science, 05 (121),* 638-644.

Soi: http://s-o-i.org/1.1/TAS-05-121-67 ***Doi***: crossref https://dx.doi.org/10.15863/TAS.2023.05.121.67

Scopus ASCC: *2611.*

Introduction

Currently, the most relevant is the solution of the optimal control problem, which is performed taking into account the uncertainty of the initial information. Uncertainty can be due to various reasons, including the inaccuracy of mathematical models. When solving problems of optimal operational control, one should also take into account possible deviations from the nominal values of a number of parameters that affect the process, but at the same time cannot be measured.

Systematic analysis of technical objects is complicated by the presence of uncertainties in physical, chemical, economic and technological information. Taking into account the uncertainty of information requires new approaches to methods of analysis, optimization and management of such systems. Modeling methods focused on the average values of the parameters, including those not fully defined, do not guarantee the optimality of the obtained solution and do not correspond to the constraints imposed on the process.

During the years of independence in our republic, special attention is paid to the automation and control of chemical-technological processes and industries. In this aspect, the creation of control systems for the ammonia synthesis process under conditions of parametric uncertainty, including perturbations in the composition of the feedstock, developed on the basis of the indicators of the technological process by building a dynamic model, developing algorithms and programs that implement automatic control systems for the modes of the ammonia synthesis column, as well as modernization and development of existing production facilities is one of the main tasks.

The development of control systems for technological processes of ammonia synthesis is a rather difficult task, which can be found in the works of scientists [1-7]. This work continues research in this direction.

The analysis of the scientific and technical literature of recent years concerning research on the development of methods for the parametric identification and synthesis of control systems for technological objects indicates the achievement of significant theoretical and practical results in this field. There are and are developing various ways of building control systems that operate under conditions of a priori parametric uncertainty [8].

At the same time, the possibilities of interval methods in the problems of synthesis of mathematical models and control systems are not sufficiently appreciated in the literature [9]. This is due to the fact that so far no concepts and a constructive methodology have been developed for constructing models and process control systems under the conditions of interval-parametric uncertainty. Methods and algorithms for formalizing and synthesizing mathematical models of control objects, estimating parameters of technological control objects, and analyzing the stability of controlled systems under interval uncertainty have been insufficiently developed. Adaptive-interval methods and algorithms for the synthesis of control systems of technological objects with complete and simplified models of control objects also require their development. These circumstances are the reason for the difference between the theoretical and practically obtained characteristics of the estimates. Sometimes these differences become significant and are of fundamental importance for deciding whether to use the results of the work of interval estimation algorithms.

Thus, at present, the level of detail, the trade-off side between the complexity, accuracy and feasibility of mathematical models of technological processes and control systems, as well as the consideration of uncertainties, are mostly expressed by heuristic considerations of the designer based on experimental data, if any. Under these conditions, it is rather problematic to talk about how effective one or another interval method is used and whether the best options for the synthesis of models and control systems are selected. In connection with the aforementioned, the development of effective interval methods for parametric identification and synthesis of control systems for technological objects in conditions of uncertainty cannot yet be considered complete.

Within the framework of global research on the development of highly efficient systems for monitoring and control of technological processes of ammonia synthesis, a significant contribution was made by the leading research centers and higher educational institutions of the world: Osaka University and Tokyo Institute of Technology (Japan) Honeywell, Imperial College London (Great Britain), “SIMSCI-Simulation” and “University of California”, “Massachusetts Institute of Technology” (USA), “Siemens” (Germany), “Korea Advanced Institute of Science and Technology” (South Korea), Russian Chemical Technological University, Moscow Institute of Fine Chemical Technology, Kazan National Research University of Chemical Technology, St. Petersburg State Technological Institute (Russia), as well as such foreign scientists as B.D. Yudina, Yu.M. Ermolyeva, A. Charnes, W.W. Cooper, G. Symonds, I. Grossmann, L. Biegler, E. Pistikopoulos, B. Liu, G.L. Degtyareva, T.K. Sirazetdinova, G.M. Ostrovsky, N.N. Ziyatdinov, T.V., Lapteva, A.F. Egorov, S.I. Dvoretsky, D.S. Dvoretsky, V.A. Kholodnov, V.I. Elizarov, V.V. Kafarov and other researchers.

A significant contribution to the solution of scientific problems, modeling, analysis and control of the ammonia synthesis process under conditions of uncertainty in Uzbekistan was made by such scientists as academicians N.R. Yusupbekov, T.F.Bekmuradov, professors Sh.M. Gulyamov, D.P. Mukhitdinov, M. A. Ismailov, Sh.N. Nuritdinov, U. V. Mannanov and others.

However, in recent years, separation processes have become significantly more complicated, requiring the creation of control and optimization systems. At the same time, due attention is not paid to the creation of highly efficient control systems based on complete dynamic models of technological processes that fully describe the relationship between the process variables.

Considerable attention is currently being paid to the problems of setting analysis, optimization and control problems for various applied areas, as well as the development of methods for their solution. However, the existing solution methods either require large computational costs or are developed for a narrow class of problems.

In Uzbekistan and abroad, in the design, modeling and analysis of chemical technological systems (CTS), specialized software is widely used - simulation programs, such as: Aspen Plus, Aspen Dynamics, Aspen HYSYS, Honeywell UniSim, ChemCAD etc. These software products allow you to create CTS models with a high-fidelity, however, in a number of cases, their functionality limits their areas of application, in particular, there are no opportunities for solving optimization problems under uncertainty. Also, there are no standard tools for describing kinetic dependencies of a special kind when simulating reaction processes.

Methodology

In the practice of designing systems for automatic and automated control of technological objects, quite often a situation occurs when the real values of individual parameters of control objects are unknown and there are no statistical descriptions of them.

Uncertainties in the parameters may appear due to various reasons:

- using simplified models that approximate a real physical process;
- incomplete estimation and identification of unknown variables;
- the presence of non-stationary coefficients in the equations of the mathematical model of the object.

In addition, the accuracy of the description of control objects can be affected, for example, by such technological factors as equipment defects, vibrations, uneven running, changes in operating modes, errors in measuring instruments, inaccuracy of scales. Operational features, such as aging and wear of equipment items, fluctuations in temperature, humidity, pressure and other external influences, can also lead to a deviation of real characteristics from nominal values. In all the cases listed above, the nature of the variations of the unknown parameters of the control systems can be considered undefined, since their changes are subject only to a priori restrictions. To solve problems of managing objects with uncertain parameters, they usually involve minimax methods, methods of stochastic control, fuzzy logic, invariance, and adaptive control. The use of a particular approach depends on the type of uncertainties and requirements for the structure and quality of management systems.

In the practice of designing systems for automatic and automated control of technological objects, quite often a situation occurs when the real values of individual parameters of control objects are unknown and there are no statistical descriptions of them. Uncertainties in the parameters may appear due to various reasons:

- using simplified models that approximate a real physical process;
- incomplete estimation and identification of unknown variables;
- the presence of non-stationary coefficients in the equations of the mathematical model of the object.

In addition, the accuracy of the description of control objects can be affected, for example, by such technological factors as equipment defects, vibrations, uneven running, changes in operating modes, errors in measuring instruments, inaccuracy of scales. Operational features, such as aging and wear of equipment items, fluctuations in temperature, humidity, pressure and other external influences, can also lead to a deviation of real characteristics from nominal values. In all the cases listed above, the nature of the variations of the unknown parameters of the control systems can be considered undefined, since their changes are subject only to a priori restrictions. To solve problems of managing objects with uncertain parameters, they usually involve minimax methods, methods of stochastic control, fuzzy logic, invariance, and adaptive control. The use of a particular approach depends on the type of uncertainties and requirements for the structure and quality of control systems.

Theoretical and practical approaches to the formalization and use of high-quality information under conditions of uncertainty are being developed to select optimal management solutions for complex systems. For dynamic systems in conditions of uncertainty, specialized estimation methods are also developed in the problems of identification and filtering. At the same time, both already developed methods of game theory and new methods related to information processing and interval analysis are also widely used.

Each of the above mathematical methods is focused on certain classes of mathematical models:

- probabilistic models;
- range;
- linguistic;
- models allowing to obtain ellipsoidal estimates of the reachability regions of phase coordinates;
- multimode models of dynamic control systems;
- interval models; mathematical models that combine both interval parameters and probabilistic characteristics.

For a more complete description of the properties of control objects in mathematical models of dynamic systems and quality criteria for the operation of closed circuits, it is also advisable to take into account the uncertainty contained in the model parameters. In addition, the adequacy of the description of the mathematical model of a dynamic system in some cases is achieved only by taking into account uncertain parameters. Often, uncertainty is an integral part of a formalized mathematical model of a controlled dynamic system.

In this paper, we will stick to the point of view that if the exact numerical value of a certain parameter is unknown (for example, measured or specified with an error), then such parameters will be considered as belonging to certain numerical intervals with known boundaries. The numerical value of this parameter will be determined by the interval - a bounded set on the number line. We will speak of a mathematical model containing indefinite parameters as an interval-indefinite model or as a mathematical model that is under conditions of interval uncertainty. The presence of interval-indeterminate parameters (interval numbers) in a mathematical model makes it difficult to apply the known methods of analysis and synthesis of control systems for dynamic objects. Therefore, the further development of interval versions of the methods for analyzing and synthesizing dynamic systems with interval uncertainty seems very relevant.

In practice, the solution of the control problem is sought according to a certain mathematical model, the accuracy of which is conditional. Various models can describe uncertainty in the values of the parameters:

1. Probabilistic (stochastic) model. It is used when an uncertainty factor can be attributed to a probabilistic, random nature. Random factors are described as probabilistic if probability density is given.
2. Statistical model. It is used when an object model is determined from the results of selective experiments under conditions of random noise and errors. In the statistical description of uncertainty factors, instead of the true moments, only estimates are obtained, the accuracy of which is determined by the experimental design, the number of experiments, interference dispersion, estimation method, etc. Thus, it is obvious that all the difficulties associated with operating with estimates of random parameters, stand up here in full.
3. Fuzzy (blurred) model. To describe the uncertainty factor in this situation, use the methods of the theory of fuzzy sets, the main provisions of which and decision-making methods are set forth. Currently, methods for solving such problems are poorly developed.
4. Interval model. Used when the range of possible parameter values is known. Interval analysis is used as a mathematical tool for solving a problem, the use of which for solving control problems became especially noticeable in the last century [10].

Experimental results.

The creation of a modern automated control system using industrial controllers allows not only increasing the economic efficiency of the enterprise, but also makes it possible to reach a new level of production process management.

In some cases, the modernization of the control system using the latest digital computer technology is, unfortunately, limited only to replacing obsolete automation tools, while not all the features and functions that modern microprocessor technology has are realized. In addition, in most cases, the control methods and methods remain the same as they were before the modernization, which ultimately cannot lead to the best management of complex technological objects, characterized, for example, by the mutual influence between adjustable parameters, the presence of disturbances, unsteadiness of dynamic characteristics objects, etc.

The paper discusses the problems of developing a system for advanced process control of ammonia synthesis. In our country and neighboring countries, there are more than thirty enterprises using the same type of ammonia synthesis reactor. This reactor is interesting, first, because it is a multidimensional control object, which is characterized by four inputs, four outputs and a significant number of disturbing influences. This, in turn, causes a number of difficulties in creating a control system and at the same time allows us to identify new ways to solve these problems.

One of the technological stages of ammonia production is the catalytic synthesis of ammonia in the column. The most important adjustable parameter is the temperature in the catalyst zone [11]. Temperature control is quite a difficult task, since the existing mathematical models are difficult to implement due to the complexity of the physicochemical dependencies. In addition, all parameters of the ammonia synthesis column vary over time.

As a research object, this work initially considered a typical chemical-technological system for the ammonia synthesis section. This chemical-technological system (CTS) was considered both separately and together with the section for the release of ammonia from purge gas. The process of producing anhydrous liquefied ammonia consists of the following stages:

- purification of the converted gas from carbon monoxide with liquid nitrogen - production of nitric mixture;
- compression of a mixture of nitric;
- synthesis of ammonia followed by cooling and condensation of ammonia gas to produce liquid ammonia;
- compression of process nitrogen;
- compression of carbon monoxide fraction and ammonia gas.

The technological scheme of the synthesis section is shown in fig. 1.

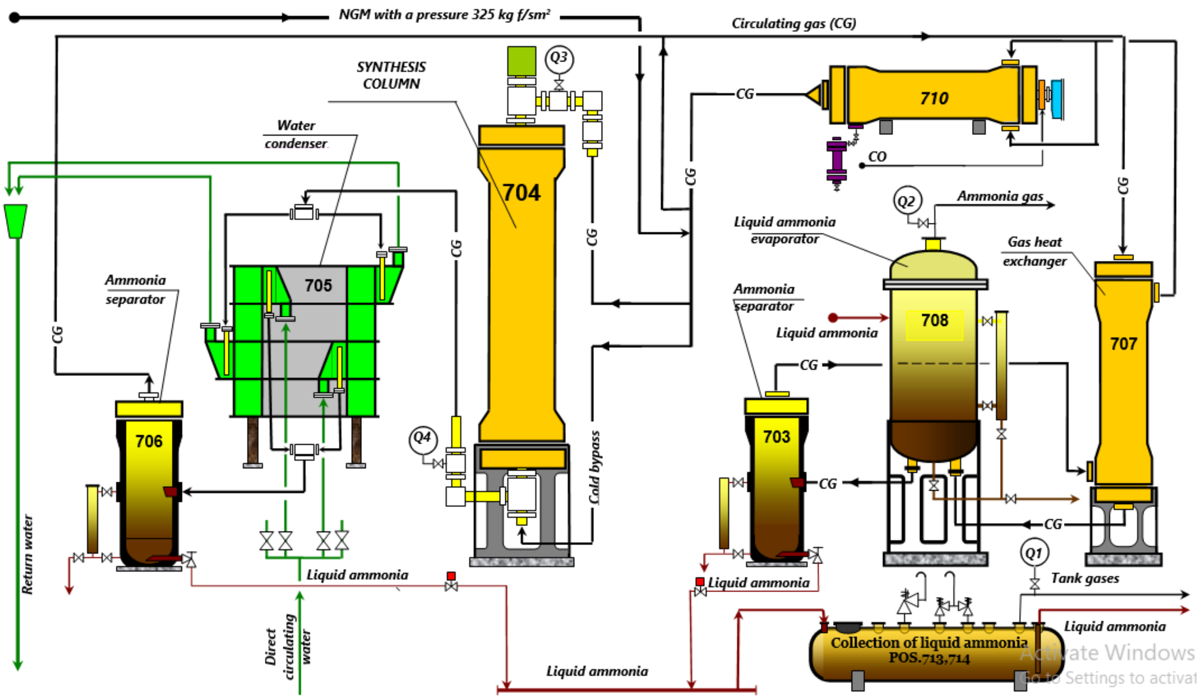

Fig. 1. Technological scheme of ammonia synthesis section.

According to the technological regulations [12], the nitrogen-hydrogen mixture (NGM) necessary for the ammonia synthesis process is obtained by cleaning the converted gas from carbon monoxide, argon, methane with liquid nitrogen.

Compressed gas compressors (pos. 710) up to a pressure of not more than 325 kg f/sm^2 (31.88 MPa) and nitrogen-hydrogen mixture is supplied to the units of synthesis of ammonia.

The process of ammonia synthesis from hydrogen and nitrogen takes place in the synthesis columns of units № 7, 8, 9 (pos. 704) on an iron catalyst at a temperature not exceeding 540 ^{0}C and a pressure not exceeding 325 kg f/sm^2.

In order to achieve the maximum performance of the reaction volume of the synthesis column, it is necessary to condense ammonia (pos. 705) most fully and separate (pos. 703,706) it from the gas mixture. NGM is cooled.

In this case, part of the ammonia goes into a liquid state and is removed from the system, the remaining gas returns to the cycle and joins the fresh gas (pos. 707,708).

The lower the temperature of NGM, the more ammonia from it condenses, and accordingly less remains in the gas. The residual volume fraction of ammonia in the gas mixture (circulating gas) at a pressure of 300 kgf/cm2, depending on temperature.

The maximum possible decrease in the temperature of the gas mixture and the improvement of the liquid ammonia separation conditions allows reducing the ammonia content at the synthesis column inlet and increasing the productivity of the column. The amount of ammonia formed corresponds to the difference of its content in the gas leaving the column and entering the column [13].

In this study, an advanced process control system for ammonia synthesis was developed and the following results were obtained (Table 1).

Table 1. Comparison table of technological indicators for the option of modernization with an advanced control system.

Parameters (technological indicators)	Before modernization	Traditional modernization	Modernization with advanced control system
Production, tons per day	1350	1800	1890
Primary reforming			
The temperature of the mixture of raw materials, °C	510	537	438
Outlet temperature, °C	820	810	706

Steam / Carbon	3.5	3.0	2.7
Secondary Reform			
T air, °C	468	480	453
Methane yield, mol %	0.32	0.27	1.72
T at the exit, °C	1002	972	885
Synthesis circuit			
CH_4 in feed gas, mol %	0.83	0.97	not
Inertness in gas, mol %	1.15	1.27	0.19
Pressure in the circuit, kg/cm^2 (excess.)	210	181	178

Conclusion

To achieve this goal the following tasks were solved:

- analysis of approaches to solving problems of building models and process control systems in conditions of uncertainty;
- formalization of the tasks of analysis and optimal control of the object under study in the context of parametric uncertainty of the initial information.
- development of the concept and methodology for constructing models and process control systems in the conditions of interval-parametric uncertainty;
- development of methods and algorithms for estimating the parameters and state of technological control objects;
- development and practical implementation of software and algorithmic support systems for solving problems of identification and synthesis of control actions under the conditions of interval uncertainty of the initial information;
- practical testing of the developed methods and computational schemes for the synthesis of process control systems based on the developed algorithms and software [10].

The main conclusions from the results of testing and trial operation of advanced process control systems are as follows [14].

Thanks to the control of the installation using advanced process control systems, it was possible to:

- increases the productivity of the reforming system by 25-30%;
- more optimal use of high potential heat;
- with parallel execution, the pressure drop is reduced;
- can be used to increase productivity, with an increase of up to 50%, as well as reduce energy consumption;
- best suited when major deficiencies are identified in areas of the furnaces and synthesis loop;
- use of excess air in a secondary reformer;
- softening the conditions in the primary reforming unit - extending the life of the pipes;
- a new stage of cryogenic treatment;
- new parallel process air compressor;
- increased CO_2 production;
- the use of pure dry synthesis gas allows achieving optimal conditions for increasing the productivity of the synthesis circuit and prolonging the life of the synthesis catalyst.

Solving these problems allows us to develop constructive methods, algorithms and computer models for parametric identification and synthesis of control systems for technological objects, contributing to an increase in the efficiency of functioning of control systems for technological objects of various functional purposes [15-18].

References:

1. Acevedo, J., & Pistikopoulos, E.N. (1998). Stohastic optimization based algorithms for process synthesis under uncertainty. *Comp. Chem. Eng*, 22, pp. 647-671.
2. Albertos, P., & Sala, A. (2004). Multivariable control systems: an engineering approach. *Springer*, 2004, 340, p. 6.
3. Amin, M. R., Sharear, S., Siddique, N., & Shaidul, I. (2013). Simulation of Ammonia Synthesis. *American Journal of Chemical Engineering.* Vol. 1, No. 3, p.59.
4. Araujo, A. (2008). Control structure design for the ammonia synthesis process / A. Araujo, S. Skogestad. *Comput. a. chem. eng*, 2008, Vol. 32, N 12, pp. 2920-2932.

5. Bonivento, C., Isidori, A., Marconi, L., & Rossi, C. (2007). Advances in control theory and application. *Springer*, 2007, 306 p.
6. Plokhotnikov, V. V. (2002). *Modal synthesis of control systems with interval parameters)*. PhD eng. sci. diss. (p.182). Novosibirsk.
7. Stepanenko, S. V. (2000). Construction of a multichannel PI regulator for temperature control in an ammonia synthesis column. Transaction of scientific papers of the *Novosibirsk state technical university*. 2000, no. 1 (18), pp. 156-159. (in Russian).
8. Khlebalin, N. Ah., & Pyatikh, D. S. (2004). *Modeling of automatic control systems with interval uncertainty of parameters.* Conf. ICCM-2004. (pp.258-266). Novosibirsk.
9. Ostrovsky, G.M. (2008). *Technical systems in conditions of uncertainty: flexibility analysis and optimization.* (p.319). Moscow: BINOM.
10. Khalilov, A.J. (2018). Analysis of approaches to solving problems of building models and control systems of technological processes in conditions of uncertainty. *Young scientist*, № 48 (234), pp. 54-57. https://moluch.ru/archive/234/54392
11. Ali, D., Kayvan, Kh., Mehdi, A., & Madjid, K. (n.d.). Modeling and simulation of ammonia synthesis reactor. *Petroleum and Coal*. 48(2), pp. 15-23. https://www.researchgate.net/publication/229034628_Modeling_and_simulation_of_ammonia_synthesis_reactor
12. (2012). *Permanent technological regulations № 24 of the complex 325 "A" of the third stage ammonia production (gas purification with liquid nitrogen, compression, synthesis).* For educational and scientific purposes, (pp.14-32). Navoi: OJSC "NAVOIYAZOT".
13. Demidenko, I.M., et al. (2001). *Ammonia: technology issues: production and practical publication*. total. ed. Yankovsky N.A, (pp.108-120). Gorlovka: Concern Stirol OJSC.
14. Khalilov, A.J. (2020). Development of an advanced control system of the process of ammonia synthesis. *International scientific journal: "Bulletin of Science and Education"* - №13 (91). Part 3., Ed. "Problems of Science" Moscow, 2020). Heading "Technical Sciences". pp. 19-22.
15. Khalilov, A.J. (2018). Computer modeling of control systems of technological processes in the conditions of parametric uncertainty. *Scientific and technical journal*. 2018 №4. Mining Bulletin of Uzbekistan, pp. 86-91.
16. Mukhitdinov, D.P., & Khalilov, A.J. (2018). The program of modeling and optimization of the technological process of ammonia synthesis. State Patent Office. *Certificate of official registration of computer programs*. № DGU 05783, 21.11.2018.
17. (2019). Modeling of ammonia synthesis process in the parametric uncertainty. International scientific journal: "*Bulletin of Science and Education"* - No. 12 (66). Part 3., Ed. "Problems of Science" Moscow, July 2019). Heading "Technical Sciences", pp. 14-17.
18. Khalilov, A.J. (2021). Modeling and Development of an Advanced Control System of the Process of Ammonia Synthesis in the Parametric Uncertainty. *International Journal of Advanced Research in Science, Engineering and Technology*. Vol. 8, Issue 5, May 2021, pp. 17466-17472.