ANNOTATION

Dissertation work of Aigul Iskakova, doctoral student of the Kazakh National Research Technical University named after K. I. Satpayev, on the topic «Development of a control system for the process of cleaning industrial gases from dust» submitted for the Doctor of Philosophy (PhD) degree in the specialty 6D070200 – «Automation and Control.»

Relevance of the work. By Decree of the President of the Republic of Kazakhstan dated February 2, 2023, № 121, a strategy for achieving carbon neutrality of the Republic of Kazakhstan until 2060 was adopted, which pays special attention to increasing production efficiency through the integrated use of raw materials, saving energy resources and protecting the environment.

Low-carbon development is a prerequisite for sustainable development and aims to prevent the catastrophic consequences of global climate change.

According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (hereinafter referred to as IPCC), anthropogenic emissions of greenhouse gases (hereinafter referred to as GHG) have reached the highest levels in human history, which is already having a significant negative impact on the Earth's climate system. This carries direct physical risks and threats to ecosystems, infrastructure, human life, and health. Countries worldwide actively take international obligations to respond to these challenges and mitigate these risks.

At the meeting of the General Assembly of the United Nations (hereinafter referred to as the UN) on September 25, 2015, the resolution "Transforming our world: the 2030 Agenda for Sustainable Development" was adopted. According to this resolution, 193 UN member states committed to ensuring sustainable, inclusive, progressive growth, social integration, and environmental protection in partnership and peace.

The Paris Agreement was adopted in December 2015. This agreement aims to support environmental integrity, a green economy, the transfer of highly efficient technologies, and adaptation to a changing climate. The main objectives of this Agreement are to keep the global average temperature below 2°C above pre-industrial levels (the level of 1850-1900) and to make efforts to limit the increase to 1.5°C.

To implement the Paris Agreement, all parties submit their climate action plans every five years - nationally determined contributions (hereinafter referred to as NDCs). Countries also develop low-carbon development strategies that provide a long-term horizon for NDCs. The main goal of these strategies is to balance anthropogenic emissions from sources and their absorption by GHG sinks.

Today, despite the renaissance of solar energy and other renewable energy sources, the bulk of electricity generation occurs in various industries worldwide. The main types of pollution in the emissions of boiler houses and thermal power plants are soot and ash - residues from the combustion of organic fuel, depending on the type of fuel (hard, wood, shale coal, fuel oil, natural gas, etc.) their amount can vary. The most common chemical compounds are sulfur and nitrogen oxides,

fluorine compounds, chlorine, hydrogen sulfide, carbon monoxide, and heavy metals.

The relationship between thermal energy and the environment is being reconsidered due to issues such as acid rain, the greenhouse effect, and increasing levels of environmental substances that are toxic to humans and wear outbuildings. The use of thermal energy is expected to grow significantly shortly, which means that the various impacts of thermal energy on the atmosphere will increase.

The most effective and widely used method of cleaning gas flows from dust is electrical cleaning in electrostatic precipitators (ESP). Significant fluctuations in the quantitative and qualitative characteristics of dusty flows negatively affect the technological modes of dust-collecting units and reduce the degree of gas cleaning. Consequently, cleaning gases from products of thermal power units and stations is one of the urgent problems. Therefore, increasing the efficiency of dust-collecting units is an important task, and the solution is to create an automated process control system (APCS) for electrical gas cleaning.

In this regard, the development of automatic control systems for electrical gas cleaning using mathematical models and control algorithms that consider the main features of the electrical gas cleaning process technology and are oriented towards modern computing technology to create an automated process control system that ensures efficient process control determines the relevance of the chosen topic.

The work aims to synthesize effective operating modes of electrostatic precipitators depending on the composition and quantity of exhaust gases from the boiler units, considering the characteristics of the fuel burned, by automating the process of electrical gas cleaning.

One of the most critical environmental protection problems is protecting the air basin from excessive pollution. Therefore, creating an automated waste gas cleaning control system should ensure the cleaning of industrial gases to acceptable levels of impurity content for emission into the atmosphere. Electrical cleaning is the most effective method of cleaning industrial gases. This cleaning method has several advantages, such as:

– wide range of productivity – from several m^3/hour to millions of m^3/hour;

– degree of gas purification – up to 99.9% and higher;

– hydraulic resistance – no more than 0.2 kPa (is the main reason for low operating costs);

– electrostatic precipitators can capture dry particles, liquid droplets, and fog particles;

– electrostatic precipitators capture particles from 0.01 microns (viruses, tobacco smoke) to tens of microns.

The peculiarity of the electrostatic precipitator's operation is that it provides the maximum degree of purification at electric field strengths in the interelectrode space when spark breakdowns occur in the electrostatic precipitator. Still, there is no transition to arc discharges. The voltage level at which spark breakdowns occur changes nonlinearly over a wide range and depends on a large number of factors: the properties of the outgoing gases, the dust content in the gas, humidity, temperature,

the size of dust particles, chemical composition, and their electrical conductivity, the conditions of layer formation on the precipitation electrodes and other factors.

With the development of environmental principles, methods for assessing the consequences of environmental pollution, the recognition of the negative impact of organic and chemical pollutants in industrial enterprises' emissions, and sanitary and hygienic standards for their production activities were approved at the legislative level. The law established the need to apply the standard of cleaning gas emissions into the atmosphere. Moreover, cleaning gas emissions containing toxic substances is mandatory in all sectors of the national economy.

Gas cleaning issues receive significant attention in government documents:

- Decree of the President of the Republic of Kazakhstan dated February 2, 2023, №121 «On approval of the Strategy for achieving carbon neutrality of the Republic of Kazakhstan until 2060»;
- Resolution of the Government of the Republic of Kazakhstan dated December 14, 2007, № 1232 «Technical Regulations Requirements for Emissions into the Environment During the Combustion of Various Types of Fuel in Boiler Plants of Thermal Power Plants»;
- Resolution of the Government of the Republic of Kazakhstan dated July 29, 2020, № 479 On approval of the Action Plan for the implementation of the Concept for the transition of the Republic of Kazakhstan to a «green economy» for 2021-2030;
- Resolution of the Government of the Republic of Kazakhstan dated March 28, 2023, № 264 On approval of the Concept for the development of energy saving and energy efficiency in the Republic of Kazakhstan for 2023-2029;
- Resolution of the Government of the Republic of Kazakhstan dated January 23, 2024, №23 Handbook of best available techniques «Fuel combustion in large installations for energy production»;
- Resolution of the Government of the Republic of Kazakhstan dated March 11, 2024, №161 Conclusion on the best available techniques «Fuel combustion in large installations for energy production»;
- Order of the Minister of Ecology, Geology and Natural Resources of the Republic of Kazakhstan dated September 9, 2021 № 367 «Rules for the operation of gas purification units».

The work aims to develop an automatic control system for cleaning industrial flue gases in electrostatic precipitators based on the following modes: distribution of flue gases among individual electrostatic precipitators, the electrical mode of the EF, and shaking of the electrodes. The system will use control synthesis with a predictive model that ensures the content of standard indicators in the exhaust gases to reduce environmental pollution.

The object of the study is a control system for the process of cleaning industrial gases from dust.

The subject of research is the automation of technological processes of gas electrical cleaning at boiler houses and thermal power plants.

Research methods – methods of the theory of systems analysis of chemical-technological processes, methods of analysis and synthesis of MIMO systems,

decomposition, methods of fuzzy logic theory, methods of constructing industrial information systems, methods of control with a predictive model.

Main objectives of the work. To achieve the set goal, it is necessary to solve the following tasks:

1) Develop an advanced control system based on chemical analysis of the composition of industrial gases.

2) Develop a multidimensional, multi-connected system for automation controlling the distribution of industrial gases among electrostatic precipitators.

3) Develop a control system for the electrical mode of electrostatic precipitators to ensure maximum purification of industrial gases with optimal energy consumption.

Develop an automatic control system for dust shaking mechanisms to ensure the most efficient dust collection in the electrostatic precipitator.

Scientific novelty:

A decomposition of the control problem of the process of electric cleaning of flue gases from dust was carried out

A new structure of the control system for cleaning exhaust gases was proposed.

3) An advanced control system was developed, taking into account the chemical analysis of industrial exhaust gases.

4) A mathematical model of the dependence of temperature on the chemical composition of gas was developed using parametric data identification

5) A MIMO control system was developed for distributing gas flows among parallel-operating electrostatic precipitators with standard regulators.

6) A fuzzy model of the control processes of the electrical mode of the ESP and shaking of the electrodes was developed

The following scientific provisions are submitted for defense:

1) The decomposition of the control problem of the process of electric cleaning of flue gases from dust was carried out

2) A new control system structure for cleaning exhaust gases was proposed.

3) An improved control system was developed, taking into account the chemical analysis of industrial exhaust gases.

4) A mathematical model of the dependence of temperature on the chemical composition of gas was developed using parametric data identification

5) A MIMO control system was developed for distributing gas flows among parallel-operating electrostatic precipitators with standard regulators.

6) A fuzzy model of controlling the ESP's electrical mode and electrode shaking was developed.

Practical value of the work. The results of theoretical and practical research presented in the work can be used as a methodological basis for developing gas cleaning in electrostatic precipitators. The constructed control system increases the efficiency of the technological process by improving the quality and efficiency of control.

Software implementation: Comprehensive software has been developed to implement the developed models and control algorithms for the industrial gas cleaning system in the MATLAB and SCADA environments.

Implementation of the results of the work. The main scientific and practical results of the dissertation work_4 Scopus, WEB of science, 5 CQAES, 7 scientific and practical conferences.

Connection with state programs. The topic of the dissertation is based on the priority areas identified in the Resolution of the Government of the Republic of Kazakhstan dated July 29, 2020, № 479 «On approval of the Action Plan for the implementation of the Concept for the transition of the Republic of Kazakhstan to a «green economy» for 2021 – 2030», which provides for a reduction in the level of carbon dioxide emissions in the electric power industry.

In addition, the Resolution of the Government of the Republic of Kazakhstan dated January 23, 2024, No. 23, "On approval of the reference book on the best available techniques "Fuel combustion in large installations for energy production," states that the best available techniques are the used and planned industry technologies, machinery and equipment that provide organizational and managerial measures aimed at reducing the level of negative impact of economic activities on the environment to ensure target indicators of environmental quality.

The Order of the Minister of Ecology, Geology, and Natural Resources of the Republic of Kazakhstan dated September 9, 2021, No. 367 "Rules for the operation of gas purification units" states that during the operation of the electrostatic precipitator, the electrical mode (current value, voltage), gas and dust loads (gas velocity in the working area, hydraulic resistance, volume and concentration of dust at the entrance to the device), temperature of the purified gas are maintained.

The scientific research presented in the dissertation was carried out within the framework of the specified Resolutions of the Government of the Republic of Kazakhstan and the order of the Minister of Ecology, Geology, and Natural Resources of the Republic of Kazakhstan.

Work approval. The main results of the dissertation work were reported and discussed at:

8th International Conference, New Electrical and Electronic Technologies and their Industrial Implementation NEET 2013, Zakopane, Poland, June 18-21, 2013; 13th International Scientific Conference on Optical Sensors and Electronic Sensors, edited by Jacek Golebiowski, Roman Gozdur, Proc. of SPIE Vol. 9291, 929108 © 2014 SPIE; Присвячується 90-річчю від дня народження академіка В.М. Глушкова, Праці міжнародноЇ науковщЇ конференціЇ, питання оптимізаціЇ обчислень (ПОО-XL), КиЇв-2013; International scientific and practical conference "Training of engineering personnel in the context of global challenges of the 21st century" within the framework of Satpayev Readings-2013; Proceedings of the II international scientific and practical conference "Information and telecommunication technologies: education, science, practice," Almaty, Kazakhstan, December 3-4, 2015; International conference, Satpayev Readings - 2018: "Innovative solutions to traditional problems: engineering and technology"; XI International scientific and technical conference "Power engineering,

infocommunication technologies and higher education" Non-profit joint-stock company "Almaty University of Power Engineering and Telecommunications named after Gumarbek Daukeev" from October 16 to 18, 2020; Satpayev Readings - 2021: "Automation and robotization".

Publications. On the topic of the dissertation, 17 scientific papers have been published, including four articles in a journal indexed in the Scopus database, four articles in a conference indexed in the Scopus database, five documents in publications recommended by the Committee for Control in the Sphere of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, and four papers in collections of international conferences.

1) Modelling and analysis of electrostatic precipitator (ESP) in the combustion process., EET' 2015 в Zakopane Przegląd Elektrotechniczny (Electrical Review) Kotyra A., Shegebayeva Zh., Imanbek B.

2) Application of Fuzzy Neural Networks in Combustion Process Diagnostics., *Energies* 2024, *17*(1), 212; https://doi.org/10.3390/en17010212., Andrzej Kotyra, Saule Smailova, Bakhyt Yeraliyeva, Saule Kumargazhanova and Baglan Imanbek

3) Experiments on the effect of control signal duty cycle on pulse gas injector closing time., ISBN 978-83-63569-49-5, 8th International Conference, New Electrical and Electronic Technologies and their Industrial Implementation NEET 2013, Zakopane, Poland, June 18-21, 2013.

4) Biomass co-combustion characterization based on analysis of flame image sequence. ISBN 978-83-63569-49-5, 8th International Conference, New Electrical and Electronic Technologies and their Industrial Implementation NEET 2013, Zakopane, Poland, June 18-21, 2014. Kotyra A.,

5) Badania eksperymentalne wplywu wypelnienia sagnalu sterujacego na czas wylaczania imulsowego wtrysku gazu., Przeglad Elektrotechiczny, ISSN 0033-2097, R.90 NR 3/2014., Mariusz Duk,

6) Application of fiber optic flame monitoring system for estimation burner input parameters. Optical Fibers and Their Applications 2014, edited by Jan Dorosz, Ryszard S. Romaniuk, Proc. of SPIE Vol. 9228, 92280O © 2014 SPIE CCC., Andrzej Kotyra, Sarsenbek Zhussupbekov.

7) Functional integration of automated system databases using artificial intelligence., ISSN: 0277-786X. ISBN: 9781510613546. Photonics applications in astronomy, communications, industry, and high energy physics experiments 2017, 28 May – 6 June Wilga, Poland.

8) Research and analysis of the physicochemical properties of coal and biomass

9) Modeling the efficiency of cleaning electrostatic precipitators with different physical and chemical properties of exhaust gases. Scientific journal "KazUTZU Khabarshysy" - "Bulletin of KazNRTU" on the journal issue: No. 3 (115). Date of publication: 2016-06-09. Zhusupbekov S.S. Estimation of Linear Model Identification of Dry filter workflow process. ТОО «Издательство «Ғылым» Национальной академии наук РК» 2016г. Wójcik W., Zhussupbekov S., Omirbekova Zh.

10) 10) Development of an intelligent process control system for dry electrostatic precipitators based on neural networks. “Intellect, idea, innovation - intelligence, idea, innovation” Multidisciplinary scientific journal of Kostanay State University named after A. Baitursynov 2016, Zhusupbekov S.S., Wojcik W., Omirbekova Zh.Zh.

11) The first case of the outbreak of the COVID-19 pandemic – the first case of the outbreak of the COVID-19 pandemic. New York Times "The First Case of the COVID-19 Pandemic" - "The First Case of the COVID-19 Pandemic" - No. 5 (123) Date: 2017-06-09.

12) Application of the Ziegler-Nichols method for discrete control systems of multi-connected objects. Bulletin of the Almaty University of Power Engineering and Communications / issn 2790-0886 / impact-factor-0.154 / 4 (55) 2021 https://doi.org/10.51775/2790-0886_2021_55_4_84., Zhusupbekov S.S. Mukhanov B.K.

13) Research active posterior rhinomanometry tomography method for nasal breathing determining violations. Sensors, 2021, 21(24), 8508 **https://doi.org/10.3390/s21248508**., Avrunin, O.G., Nosova, Y.V., Abdelhamid, I.Y., Harasim, D.

Structure and volume of the dissertation. The dissertation consists of an introduction, six sections, a conclusion, and a list of references from 100 titles, presented on 129 pages of computer text, including 62 figures, 15 tables, and 15 appendices.