Algorithm for Selection Equipment to Reduce the Technogenic Effect on the Environment

Kozii I.S., Plyatsuk L.D., Koval V.V.
Sumy State University
Sumy, Ukraine

Abstract. The work is devoted to the development of an algorithm for selection dust and gas purification equipment in order to reduce the anthropogenic impact on the environment from emissions of the heat, power and chemical industries, which are sources of complex environmental pollution. The need for the research was necessitated by the inefficiency of environmental measures taken due to the huge number of devices with different designs for emissions' purification, their non-universality and low efficiency of the purification systems. The main goal of the study was to develop a software algorithm for the reasonable choice of the optimal dust and gas purification equipment, taking into account the actual conditions of the technological environment and the characteristics of pollutants. The goal was achieved using a logical and mathematical description of the pollutant parameters, environmental conditions and process equipment parameters. The uniqueness of the developed algorithm consisted of rechecking the compliance of each equipment parameter with environmental conditions and pollutant characteristics. The most important aims were to obtain an algorithm for selection efficient equipment, taking into account its parameters and initial characteristics of pollutants and environmental conditions, the simplicity and accessibility of its implementation for a wide number of industrial facilities in the heat, power and chemical industries. The proposed algorithm, in contrast to the approaches used in practice, was characterized by the work flexibility due to the possibility of supplementing and improving the databases of pollutants and equipment.

***Keywords*:** technogenic load, dust and gas emissions, purification systems, selection algorithm, equipment, solution efficiency.

DOI: https://doi.org/10.52254/1857-0070.2022.1-53.05

UDC: 621.162.252

Algoritm de selectare a echipamentelor pentru reducerea poverii tehnogene asupra mediului înconjurător

Cozii I.S., Pliațuc L.D., Covali V.V.
Universitatea de Stat din Sumî, Sumî, Ucraina

Rezumat. Lucrarea este dedicată elaborării unui algoritm de selectare a echipamentelor de purificare a pulberilor și gazelor pentru reducerea impactului tehnogen asupra mediului înconjurător al emisiilor din industria termoenergetică și chimică. Scopul principal al studiului este de a elabora un algoritm pentru selectarea echipamentului optim de purificare a prafului și a gazelor, luând în considerare condițiile reale ale mediului tehnologic și caracteristicile poluanților. Obiectivul stabilit este atins prin intermediul descrierii logice și matematice a considerării simultane a parametrilor poluanților, a condițiilor mediului și a parametrilor echipamentelor tehnologice. Unicitatea algoritmului elaborat constă în verificarea încrucișată a conformității fiecărui parametru al echipamentului cu condițiile mediului și caracteristicile poluanților. Cele mai importante rezultate constau în obținerea algoritmului de alegere a echipamentului eficient, ținând cont de parametrii săi și de caracteristicile inițiale ale poluanților și de condițiile mediului, simplitatea și accesibilitatea implementării sale pentru o gamă largă de obiective industriale a ramurilor termoelectrică și chimică. Semnificația rezultatelor cercetării constă în faptul că: 1) în premieră se formează o bază de date a poluanților, a condițiilor mediului tehnologic și a parametrilor echipamentelor de purificare a pulberii și gazelor în ceea ce privește parametrii energetici, termici, tehnici, structurali și sanitaro-igienici; 2) este asigurată rapiditatea de prelucrare a bazelor de date pentru selectarea optimală a echipamentelor din contul comparării consecutive a parametrilor inițiali a substanțelor poluante și a condițiilor mediului de desfășurare a procesului de purificare. Algoritmul propus, spre deosebire de abordările aplicate în practică, se distinge prin flexibilitatea de funcționare din contul posibilității prevăzute de completare și perfecționare a bazelor de date a substanțelor poluante și a echipamentelor.

Cuvinte-cheie: mediu, povară tehnogenă, emisii de pulbere și gaze, sisteme de purificare algoritm de selectare, echipamente, eficiența soluției.

Алгоритм выбора оборудования для снижения техногенной нагрузки на окружающую среду

Козий И.С., Пляцук Л.Д., Коваль В.В.,
Сумский государственный университет, Сумы, Украина

Аннотация. Работа посвящена разработке алгоритма выбора пылегазоочистного оборудования для снижения техногенного воздействия на окружающую среду от выбросов предприятий теплоэнергетики и химической отрасли, которые являются источниками комплексного загрязнения окружающей среды. Необходимость исследования обусловлена неэффективностью принимаемых природоохранных мероприятий из-за огромного количества различных конструкций аппаратов для очистки выбросов, их не универсальностью и низкой эффективностью работы систем очистки. В результате, в атмосферу поступают пылегазовые выбросы, которые в основном содержат мелкодисперсные взвешенные капли жидкости и различные по дисперсному составу взвешенные твердые частицы. Основной целью исследования является разработка алгоритма выбора оптимального пылегазоочистного оборудования с учетом реальных условий технологической среды и характеристик загрязняющих веществ. Поставленная цель достигается посредством логического и математического описания одновременного учета параметров загрязняющих веществ, условий среды и параметров технологического оборудования. Уникальность разработанного алгоритма состоит в перепроверке соответствия каждого параметра оборудования условиям среды и характеристикам загрязняющих веществ. Наиболее важные результаты состоят в получении алгоритма выбора эффективного оборудования с учетом его параметров и исходных характеристик загрязняющих веществ и условий среды, простоте и доступности ее реализации для широкого числа промышленных объектов теплоэнергетической и химической отраслей. Значимость результатов исследования состоит в том, что: 1) впервые сформировано базы данных загрязняющих веществ, условий технологической среды и параметров пылегазоочистного оборудования с учетом энергетических, тепловых, технических, конструктивных и санитарно-гигиенических параметров; 2) обеспечена быстрота обработки баз данных для оптимального выбора оборудования, за счет последовательного сопоставления исходных параметров загрязняющих веществ и условий среды проведения процесса очистки. Предложенный алгоритм, в отличии от применяемых на практике подходов, характеризуется гибкостью работы за счет предусмотренной возможности дополнения и усовершенствования баз данных загрязняющих веществ и оборудования.

***Ключевые слова*:** окружающая среда, техногенная нагрузка, пылегазовые выбросы, системы очистки, алгоритм выбора, оборудование, эффективность решения.

INTRODUCTION

According to the degree of a chemical danger to humans caused by the atmospheric air pollution is of primary importance. In order to assess the degree of technogenic impact on the environment, considerable attention was paid to the study of pollutant emissions as a key factor in the formation of zones of ecological disaster.

The production of electricity, heat and chemical industry products to meet the needs of society leads to an increase in the negative impact on the environment and increases the risk of diseases for the population [1–5]. The works of a number of researchers are devoted to the negative impact of thermal power plants and chemical enterprises on the atmospheric air and to the search for the ways to solve this problem [6–9].

Thermal power and chemical enterprises are severe sources of complex environmental pollution [10, 11]. Due to the imperfection of technological processes and the unsatisfactory operation of purification systems, gases at of these enterprises enter the atmosphere, which contain compounds of various toxicity, finely dispersed suspended liquid droplets, solid particles (dust) of the initial material and products, etc.

Traditionally, most of the energy and chemical industrial enterprises, present antipollution schemes by dry and wet types of purification devices.

As dry cleaning devices, cyclones, electrostatic precipitators and bag filters are mainly used [12–14]. These types of dry cleaners are used to capture suspended solids, but they cannot work effectively with gas streams that contain easily sticky, tarry substances and fine dust.

Wet dust and gas purifying devices are mainly represented by spray and plate scrubbers, vortex-type devices, etc. [15, 16]. In general, wet cleaning requires no additional gas preparation; it allows simultaneous purification both of gas emissions and dispersed particles. Wet dust collection is highly efficient in capturing fine dust, however the problem of gas purification from easily sticky and tarry substances excludes the possibility of efficient use of wet type apparatuses.

The analysis of the main types of dust and gas purifying equipment and systems for processing databases of this equipment are extensively presented in the scientific literature. The integration of the equipment characteristics and parameters of the technological process for an informed decision on the equipment selection is fairly time-consuming [17–20]. The complexity of the proposed approaches lies in the bulkiness of the equipment databases, a limited list of characteristics of pollutants, and narrow focus of the equipment selection for compliance, mainly, with technical requirements [21, 22].

Further research requires the direction of a scientifically based choice of certain designs of facilities, taking into account the actual conditions of the technological environment and the characteristics of pollutants.

Protection of the environment is the key goal for the sustainable development of society. Therefore, selection of the optimal technological solutions for purification of emissions necessitates the development of software solutions and the relevance of studying the ways to reduce the technogenic burden on the environment.

MATERIALS AND METHODS OF RESEARCH

The problem of a reasonable choice of the optimal dust and gas purification equipment is that it is necessary to take into account the parameters of pollutants and environmental conditions for the purification process [23, 24].

In general, the selection methodology of the optimal technological solutions [25] for purification dust and gas emissions is presented in Fig. 1. The scheme is a combination of three elemental blocks:

– pollutant;
– circumstance's parameters;
– dust and gas purification equipment.

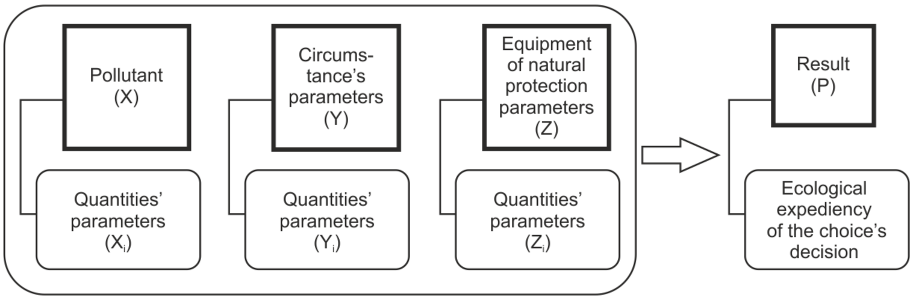

Fig.1. An example of inserting a figure into the text on the entire width of a sheet.

The ratio of these blocks to each other gives a certain ecological and technological result of applying a technological solution in the case of a specific pollutant.

Each of the above blocks (X, Y, Z) can be represented by a set of characteristics of its parameters (X_i, Y_i, Z_i).

To develop an algorithm for selection dust and gas purification equipment, the method for sequential hierarchial clustering (SHC) is used [26]. According to the mathematical logic principles, a preset element (object), taking into account its characteristics, can be represented as a cluster dendrogram (Fig. 2), where each cluster is responsible for a certain parameter.

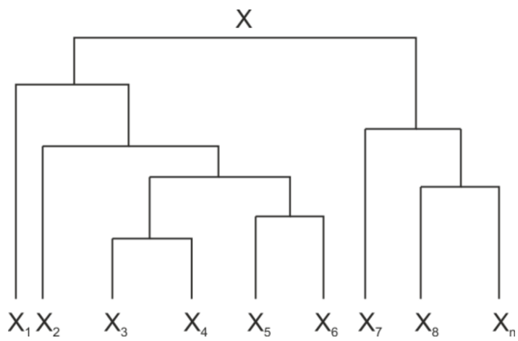

Fig.2. Cluster dendrogram of object X.

The ranking (hierarchy) of the dendrogram branches should include the validity of the technical or environmental characteristics of a given element block, which is determined based on the objectives of the task.

Cophenetic correlation or various rank indices can be used to quantify differences between clustering options. The use of principle components (X, Y, Z) for hierarchial clustering is one of the possible ways to hybridize algorithms, which progressively attracts the attention of specialists. Advantages of the hierarchial cluster procedures:

– in comparison with other cluster procedures, they ensure a more complete and subtle analysis of the structure of the set of observations under study;

– there is a possibility of the analysis visual interpretation based on the dendrogram.

Taking into account the successive hierarchical comparisons of the elements of the bases equipment parameters, environmental conditions and pollutant characteristics (X_i, Y_i, Z_i), an updated block diagram was obtaibed of the conditions for selection technological equipment (Fig. 3).

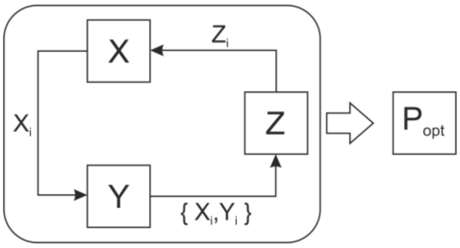

Fig.3. Scheme of sequential selection of clusters of conditions for choosing a technical solution.

The conditions for selection each of the optimal parameters (Z_i^{opt}) of dust and gas purification equipment corresponds to the following equation:

$$Z_i^{opt} = f\left(X_i, Y_i\right). \quad (1)$$

Resulting from the selection of all parameters of dust and gas purification equipment for compliance with the conditions of the process environment and the characteristics of pollutants, the final result from a variety of the devices' configurations can be represented by the expression:

$$\lim_{n\to\infty} P_{opt} \in \left\{Z_1, Z_2, \ldots, Z_i\right\} - opt. \quad (2)$$

For simplification and accessibility of the software algorithm for the implementation of the optimal choice of the technological solutions to reduce emissions into the atmosphere, the spreadsheet editor was used.

RESULTS AND DISCUSSION

To implement the software algorithm for selection the nature protection equipment in the spreadsheet editor environment, we will form a database of the studied parameters of the system for selection the dust and gas purification equipment in the form of separate spreadsheet tabs.

Database of pollutants. The database of pollutants is formed as a two-dimensional matrix. The database contains information on a certain list of pollutants, including their different types, physico-chemical and sanitary-hygienic parameters, which are necessary to make justified decisions on the equipment selection. The importance of various characteristics of pollutants is determined versus the purpose of the study – both technological and sanitary-hygienic preference is possible. The database information is formed based on production of the inventory data, technological process conditions and reference data on certain pollutants.

Each cell of the database of pollutants in our case is a characterization of the i-th pollutant and includes the following parameters: the first column is the name (code) of the pollutant.

X_1 – state of aggregation of the pollutant. This parameter affects the choice of the method for purification the production emissions. For the further calculations' convenience, it was assumed that the solid state is taken equal to 0, liquid and gaseous - 1.

X_2 – dispersion of the pollutant, μm. This parameter limits the use of apparatuses where a "breakthrough" of particles of a certain size is possible and, accordingly, it will affect the efficiency of the process equipment.

X_3 – pollutant density, mg/cm^3. This is a physical parameter of the test substance, which is taken from the references or laboratory data reference and can affect the operation of the treatment equipment.

X_4 – the pollutant particles' shape. This parameter will be used to describe the physical form of solid pollutants and, it can affect the behavior of the pollutant air flow inside the gas purification equipment. For the isometric shape of particles, we shall accept value 3, laminar particles – 2, and fibers – 1.

X_5 – pollutant hazard class. This is a sanitary and hygienic parameter, which is accepted depending on the current sanitary standards in the range from 1 to 4.

X_6 – effect on the human body. This is a sanitary and hygienic parameter, which depends on the consequences of a pollutant exposure on the human body. For substances that cause irritation / damage to the skin, we use value 3, respiratory / fibrogenic effect – 2, toxic / carcinogenic effect – 1.

X_7 – the chemical pollutant composition, which will be used as an information display of the substance composition and for possible chemical reactions in the chemisorption apparatuses.

X_8 – maximum allowable concentration of a pollutant, mg/m^3. This is a sanitary and hygienic parameter that will indicate the potential danger of a pollutant for humans.

X_9 – adhesion of pollutant particles, expressed in terms of the mechanical strain to break the particles' layer, Pa. We will use this parameter when compiling the equipment database.

X_{10} – combustibility of pollutant particles. For combustible substances, we take value 1, non-combustible - 0. This parameter is a limitation for the use of equipment that contains combustible materials and high operational temperatures.

X_{11} – wettability of pollutant particles, ^{o}. This physical parameter is determined for solid pollutants under laboratory conditions.

X_{12} is the water solubility of a pollutant, which can affect the process of trapping substances in wet type apparatuses. For soluble substances, we accept value 2, poorly soluble – 1, and insoluble – 0.

X_{13} – the capacity to absorb pollutants (sorption) of environmental components. For sorbent substances, we use value 1, for substances that are not capable of absorption, 0.

X_{14} – the capacity of a pollutant to enter into a chemical reaction. This chemical parameter makes it possible to use wet purification methods (chemisorption) with the pollutant being neutralized.

This list of physico-chemical and sanitary-hygienic parameters of pollutants can be expanded depending on the desired final result of the choice of a technological solution.

To sum up the information on the database of pollutants, we present a database for specific pollutants of enterprises in the heat and power industry and the chemical industry in (Table 1).

Table 1

Example of a database of pollutants in the heat and chemical industry

Pollutant	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
Titanium dioxide aerosol	0	0,26	2920	3	4	2	TiO_2	10	780	0	36	0	0	0
Ilmenite pilus	0	7,20	3600	3	4	2	$FeTiO_3$	10	320	0	72	0	0	0
Sulfur dioxide	1	-	2,619	-	3	2	SO_2	10	-	0	-	2	1	1
Nitrogen dioxide	1	-	2,052	-	3	2, 3	NO_2	2	-	0	-	2	1	1
Sulphuric acid	1	-	1836	-	2	1, 2, 3	H_2SO_4	1	-	0	-	2	1	1
Carbon dioxide	1	-	1,839	-	4	2	CO_2	3	-	0	-	2	1	1

Database of process environmental parameters. By analogy, a database is formed as a matrix of environmental parameters (conditions for ensuring the purification process) during the emissions inflow containing pollutants from the source of formation. The condition matrix includes the following parameters:

The first column – specific environmental conditions, characterized by a set of conditions during the release of pollutants and determining the selection of parameters for the implementation of technical solutions.

Y_1 is the moisture content condition of the pollutant emission. For the moisture-containing emissions, we accept value 1 (we mean that pollutants are emitted accompanied by a significant moisture content), dry pollutant emission – 0. This technological parameter influences the choice of a following method for emissions' purification (dry, wet) from the process equipment base.

Y_2 – condition for the maximum volume of emissions, m^3/h. This technological parameter affects the choice of a certain technological solution, considering its purification capacity.

Y_3 is the condition for the maximum temperature of the pollutant emissions, ^{o}C. This parameter restricts the choice of technological equipment according to the temperature regime of purification.

Y_4 is a condition for the presence of foreign impurities in addition to a specific pollutant. In the presence of foreign impurities, we accept value equal to 1, in the absence of foreign impurities – 0. This technological parameter can complicate the process of purification from substances that can enter a chemical reaction and requires, as an option, the use of more complex technological solutions.

Table 2

Environmental Conditions Database

Type of conditions	Y_1	Y_2	Y_3	Y_4
1 variant	0	3000	100	0
…	…	…	…	…
n variant	0 or 1	…	…	0 or 1

A generalization of the parameters' matrix of the environmental technological conditions is shown in Table 2.

Database of parameters of dust and gas purification equipment. The third key block of the study is the formation of a matrix of parameters of dust and gas purification equipment that can be used to remove pollutants (occuring at a particular industrial enterprise or potentially possible for use) and which takes into account the following parameters:

The first column is the name of the dust and gas purification equipment.

Z_1 – the parameter of the device responsible for the possibility of dry or wet purification. For the wet type devices, we take value 1, for the dry method – 0. In order of importance, this is a significant indicator that we propose to use first for a further selection of the technological solutions.

Z_2 is the maximum load of the gas phase apparatus, m^3/h. This technological parameter characterizes the capacity of the apparatus for purification of the dust and gas flow of a pollutant.

Z_3 – hydraulic resistance of the apparatus, Pa. This technological parameter of the equipment takes into account the energy losses during the dust and gas flow in the purification process with the apparatus use.

Z_4 – permissible concentration of a pollutant at the input to the apparatus, g/m^3. This technological parameter characterizes the capacity of stable operation of the equipment at certain concentrations of the pollutant that is supplied for the treatment.

Z_5 is the minimum value of the pollutant concentration at the apparatus output, mg/m^3. This parameter depends on the efficiency of the equipment at the optimal parameters of the workflow.

Z_6 is the efficiency of the fractional composition capture of pollutant particles (minimum particle size), μm. This process parameter refers to solid contaminants that can be captured using certain dust and gas purification equipment, taking into account possible deposition mechanisms.

Z_7 is the upper temperature limit of the possible operation of the apparatus, °C. This process parameter can be used as a temperature limit to exploit certain environmental conditions and contaminant properties.

Z_8 is the maximum gas velocity in the apparatus section, m/s. This parameter depends on different hardware designs. For example, for the Ventruri scrubber this will be the maximum gas velocity up to the confuser; for tray apparatuses it will be the velocity in the inter-plate section of the apparatus.

Z_9 is the flow rate of the absorbing liquid, m^3/h. This parameter is used for the wet purification devices and is characterized by the maximum flow rate of the absorbing liquid for the processes of deposition/chemisorption of pollutants.

Z_{10} is an equipment parameter that is responsible for the capacity to work with sticky pollutant particles. For the devices that can effectively work with sticky particles, we will take value 1, whereas for the devices that are not capable to purify the gas flow from sticky particles it will be 0.

A generalized database of dust and gas purification equipment is given in Table 3 [12, 13, 15].

If necessary, the base of equipment can be expanded taking into account various additional equipment or its parameters.

The principle of operation of the sequential hierarchial clustering algorithm will consist in sequential comparison of various parameters (clusters) of the three databases. Depending on the ultimate goal of the comparative analysis, it is possible to rank the value of clusters of various technical or environmental components of blocks X, Y, Z (Fig. 3).

The analysis of clusters of databases of pollutants, technological conditions of the environment and equipment is carried out using the spreadsheet editor. It is convenient to save the final software product in *.xlsx format for the following work at any device that supports this data format.

As an example, let us consider the application of this algorithm in order to optimally select equipment for purification the emissions with a volume of 5000 m^3/h at a temperature of 80 °C from finely suspended titanium dioxide particles (aerosol), which contain additional moisture and foreign pollutants.

In order to sequentially compare clusters of the three databases, the formal conditions, built-in logical commands and truth tables to recheck the comparison results are used. First, a comparison is performed of parameter Z_1=0 according to 18 values from the bases X, Y. In parallel, we carry out the selection according to Z_1=1. In the case of a full match, a maximum of 18 TRUE values can be obtained. In the matching example, 17 TRUE values were obtained. Parallel calculation for Z_1=1 gave the maximum result of TRUE values, so we carry out the next stage of comparing the parameters Z_2, Z_3, ..., Z_{10} with the database parameters X, Y.

Table 3

Example of a database of pollutants in the heat and chemical industry

Name of the dust and gas purification equipment	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}
EGU type electrostatic precipitator (EGU 1-7/400-4-4/2.56-2-11.2)	0	36200	200	90	50	0,1	330	1	-	1
Electric precipitator resin tubular – CP EPRT-11,4-4-SH	0	40500	200	6	20	0,1	330	1	-	1
Sleeve filter with impulse regeneration – SFIR-25	0	2400	2000	10	20	0,3	135	0,55	-	0
Sleeve filter with impulse regeneration – SFIR-1200	0	110000	2000	10	20	0,3	135	0,55	-	0
Two-stage bag-cartridge filter – SB5CF*6 (6 sections)	0	30000	2500	120	1	1	240	0,15	-	0
Battery cyclone – BC-512 (one section)	0	6500	1300	75	10000	10	400	4	-	1
Wet scruber Venturi 150/90-800	1	7000	1200	30	500	1	400	5	7	1
Apparatus with Large Holes Sieve Trays (d_o = 0.06 m)	1	40000	1200	20	50	0,3	400	3,5	10	1
Absorber SHV-50	1	50000	3500	30	100	0,5	300	10	10	1

As a result of sequential comparison of the parameters of the three databases (X, Y, Z), we obtained the final values of the optimal parameters Z_i for the above problem. The application of logical filters matching Z_i parameters for the equipment base, leads to the recommended result of using the Apparatus with Large Holes Sieve Trays (d_o = 0.06 m) out of 9 proposed technical solutions in the Z equipment base.

For the convenience of the review of the initial conditions of the algorithm selection in the spreadsheet editor, a separate sheet has been added, in which the possibility of selection a pollutant and environmental conditions from databases X, Y (Fig. 4) is implemented.

	Column letter		D													
	Column number in the table		1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Parameter index		X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
Pollutant selection	Titanium dioxide aerosol	1	0	0,26	2920	3	4	2	TiO2	10	780	0	36	0	0	0
	Column letter		D													
	Column number in the table		1	2	3	4										
	Parameter index		Y1	Y2	Y3	Y4										
Choice of conditions	1 variant	1	1	5000	80	1										

Fig.4. Sheet of initial conditions for choosing a technical solution.

As a result of the work performed, the algorithm for choosing the optimal dust and gas purification equipment for reducing emissions of pollutants into the atmosphere is implemented on

6 tabs of the spreadsheet editor. In the case of selection several technical solutions from the equipment base that satisfy the parameters of the pollutant and the technical conditions of the environment, a secondary selection is possible based on the material and technical or environmental characteristics of the equipment.

CONCLUSION

This work proposed and implemented a methodology for selection dust and gas purification equipment to reduce pollutant emissions in thermal power and chemical industry in the software environment of the spreadsheet editor. Using the spreadsheet editor simplifies the use of the equipment selection technique and makes it available to a wide number of users on computers that support *.xlsx files or online.

The software algorithm is based on the method of sequential hierarchial clustering and comparison of the parameters of three databases: the characteristics of pollutants, the technological conditions of the environment and the parameters of dust and gas purification equipment. Sequential comparison of the characteristics (clusters) of databases allows obtaining the optimal value of the characteristics of the technological solution, taking into account the characteristics of the pollutant and the environmental conditions of this process. In order to sequentially compare clusters of three databases, formal conditions, built-in logical commands, and truth tables of parameter matching conditions were used.

The proposed algorithm and its implementation are characterized by high efficiency and differ from existing approaches in the speed of data processing and flexibility of using, the possibility of supplementing databases of pollutants and process equipment.

REFERENCES

[1] Gedik K., Imamoglu I. A Preliminary Investigation of the Invironmental Impact of a Thermal Power Plant in Relation to PCB Contamination. *Environmental Science and Pollution Research*, 2011, vol. 18, pp. 968-977.

[2] Mishra U.C. Environmental Impact of Coal Industry and Thermal Power Plants in India. *Journal of Environmental Radioactivity*, 2004, vol. 72, pp. 35-40.

[3] George J., Masto R.E., Ram L.C., Tarit B. Das Human Exposure Risks for Metals in Soil Near a Coal-Fired Power-Generating Plant. *Archives of Environmental Contamination and Toxicology*, 2015, vol. 68, pp. 451-461.

[4] Liao M.C., Lan K, Yao Y. Sustainability Implications of Artificial Intelligence in the Chemical Industry: A conceptual Framework. *Journal of industrial ecology*, 2021, pp. 1-19. doi: 10.1111/jiec.13214.

[5] Ahmad T., Zhang D., Huang C., Zhang H., Dai N., Song Y., Chen H. Artificial Intelligence in Sustainable Energy Industry: Status quo, Challenges and Opportunities. *Journal of Cleaner Production*, 2021, vol. 289, 125834. doi: 10.1016/j.jclepro.2021.125834.

[6] Popescu L.G., Popa R.G., Schiopu E.C. The Thermal Power Plant Impact on the Environment and Some Possibilities of Reduce It by Ash and Slag Recycling and Reuse. *Scientific Papers-Series e-Land Reclamation Earth Observation & Surveying Environmental Engineering*, 2018, vol. 7, pp. 10-15.

[7] Gang X., Yong-ping Y., Shi-yuan L., Le L., Xiaona S. Comprehensive Evaluation of Coal-Fired Power Plants Based on Grey Relational Analysis and Analytic Hierarchy Process. *Energy Policy*, 2011, vol. 39, pp. 2343-2351.

[8] Chuanyong Z., Hezhong T., Ke C. Potentials of Whole Process Control of Heavy Metals Emissions from Coal-Fired Power Plants in China. *Journal of Cleaner Production*, 2016, vol. 114, pp. 343-351.

[9] Singh R.K., Gupta N.C., Guha B.K. The Leaching Characteristics of Trace Elements in Coal Fly Ash and an Ash Disposal System of Thermal Power Plants. *Energy Sources, Part A: Recovery, Utilization and Environmental*, 2012, vol. 34, pp. 602-608.

[10] Hoang V.N., Alauddin M. Input-Orientated Data Envelopment Analysis Framework for Measuring and Decomposing Economic, Environmental and Ecological Efficiency: An Application to OECD Agriculture. *Environmental and Resource Economics*, 2012, 51(3), pp. 431-452. doi: 10.1007/s10640-011-9506-6.

[11] Aljundi I.H. Energy and Exergy Analysis of a Steam Power Plant in Jordan. *Applied Thermal Engineering*, 2009, vol. 29(2-3), pp. 324–328. doi: 10.1016/j.applthermaleng.2008.02.029.

[12] Ladygichev M.G., Berner G.YA. *Zarubezhnoe i Otechestvennoe Oborudovanie Dlya Ochistki Gazov: Spravochnoye Izdanie* [Foreign and Domestic Gas Purification Equipment: Reference Publication]. Moscow: *Teplotekhnik – Heat Engineer*, 2004. 696 p. (In Russian).

[13] Aliyev G.M. *Tekhnika Pyleulavlivaniya i Ochistki Promyshlennykh Gazov: Spravochnoye Izd*. [Technique of Dust Collection and Purification of Industrial Gases: Reference ed.] –

Moscow: *Metallurgiya – Metallurgy*, 1986. 544 p. (In Russian).

[14] Amza Gh., Nitoi D., Amza Z., Petrescu V., Radu C. [Researches Concerning the Construction of Ultrasonic Gas Filters]. *IOP Conf. Series: “Materials Science and Engineering”.* IOP Publishing, 2018, 022004. doi:10.1088/1757-899X/400/2/022004. (In English).

[15] Straus V. *Promyshlennaya Ochistka Gazov* [Industrial Gas Cleaning]. – Moscow: *Khimiya – Chemistry*, 1981. 616 p. (In Russian).

[16] Borisenko A.V. *Novye Tekhnologii Ochistki Gazov ot Vzveshennykh Tverdykh i Zhidkikh Chastits, Parogazovykh Primesey v Voprosakh i Otvetakh* [New Technologies for Gas Purification from Suspended Solid and Liquid Particles, Vapor and Gaseous Impurities in Questions and Answers]. – Karaganda: *Izdatel'stvo KSTU – KSTU Publishing House*, 2018. 178 p. (In Russian).

[17] Mokrozub V.G., Farakhshina I.V., Al-Magsusii H.F.H. Selection of Equipment Types when Designing Multipurpose Chemical Plants. *Chemical and Petroleum Engineering*, 2020, vol. 56, pp. 230-236. doi:10.1007/s10556-020-00763-2.

[18] Borisenko A.V., Karpushkin S.V. Hierarchy of Processing Equipment Configuration Design Problems for Multiproduct Chemical Plants. *Journal of Computer and Systems Sciences International*, 2017, vol. 53(3), pp. 410-419.

[19] Mokeddem D., Khellaf A. Optimal Solutions of Multiproduct Batch Chemical Process Using Multiobjective Genetic Algorithm with Expert Decision System. *Journal of Automated Methods and Management in Chemistry*, 2009, Art. ID 927426.

[20] Lee J.H., Shin J., Realff M.J. Machine Learning: Overview of the Recent Progresses and Implications for the Process Systems Engineering Field. *Computers and Chemical Engineering*, 2018, vol. 114, pp. 111-121. doi: 10.1016/j.compchemeng.2017.10.008.

[21] Cao J., Mozaffar M., Garcia D.J., Ehmann K., Ren H., You F., Correa, J.E. Sustainable Manufacturing with Cyber-Physical Discrete Manufacturing Networks: Overview and Modeling Framework. *Journal of Manufacturing Science and Engineering*, 2018, 141(2), 021013. doi: 10.1115/1.4041833.

[22] Choy K.L., Ho G.T.S., Lee C.K.H., Lam H.Y., Cheng S.W.Y., Siu P.K.Y., Pang G.K.H., Tang V., Lee J.C.H., Tsang Y.P. A Recursive Operations Strategy Model for Managing Sustainable Chemical Product Development and Production. *International Journal of Production Economics*, 2018, vol. 181, pp. 262-272. doi: 10.1016/j.ijpe.2016.07.011.

[23] Ali J.M., Hussain M.A., Tade M.O., Zhang J. Artificial Intelligence Techniques Applied as Estimator in Chemical Process Systems – A Literature Survey. *Expert Systems with Applications*, 2015, vol. 42(14), pp. 5915-5931. doi: 10.1016/j.eswa.2015.03.023.

[24] Behdani B., Lukszo Z., Srinivasan R. Agent-Oriented Simulation Framework for Handling Disruptions in Chemical Supply Chains. *Computers and Chemical Engineering*, 2019, vol. 122, pp. 306-325. doi: 10.1016/j.compchemeng.2018.
09.027.

[25] Ferrer J.B., Negny S., Robles G.C., Le Lann J.M. Eco-Innovative Design Method for Process Engineering. *Computers and Chemical Engineering*, 2012, vol. 45, pp. 137-151. doi: 10.1016/j.compchemeng.2012.06.020.

[26] Ruijters E., Stoelinga M. Fault Free Analysis: A Survey of the State-of-the-Art in Modeling, Analysis and Tools. *Computer Science Review*, 2015, vol. 15, pp. 29-62.

Information about authors.

Kozii Ivan Sergeyevich – PhD, Associate Professor. Research interests: processes and equipment of environmental technologies, modeling of the environment.
E-mail: i.koziy@ecolog.sumdu.edu.ua

Plyatsuk Leonid Dmitrievich – Doctor of Science, Professor, Academician of Engineering Academy of Ukraine. Research interests: processes and equipment of environmental technologies, E-mail: l.plyacuk@ecolog.sumdu.edu.ua

Koval Vitaliy Voktorovich – PhD, Senior Lecturer. Research interests: modern information technologies.
E-mail: v.koval@dcs.sumdu.edu.ua