

Classification of Separation Equipment by Design and Technological Features

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Abstract

Production range increasing causes many obstacles to ensure the work of the chemical industry. Production must respond quickly to the slightest change and must be customer-oriented. Due to this, there is a general trend towards increasing production flexibility by introducing modular systems. Thus, there is a need to classify existing solutions to develop flexible systems based on them. The article contains the analysis of chemical industry development tendencies, a methodology of research of modular separation devices, and their classification by design and technological features. The study result is a design and technological classification with a code that can optimize various separation devices. As a result of experimental research, preliminary and acceptance tests of experimental samples, the main hydrodynamic and separation characteristics of modular separation devices and combined multifunctional separators are determined: hydraulic resistance 0.15–2.00 kPa for units and 15–30 kPa for devices; effective capture of particles from the size of 5 μm; efficiency of separate stages of modular separation devices is about 70–90 %; efficiency of combined multifunctional separators is approximately 99.5–99.9 %. The offered multipurpose separators equipped with dynamically regulated modular separation devices do not concede to world analogs by the main technical characteristics of combined multistage separators worldwide.

Keywords: modular separation device, technological classification, flexible assembly.

Received on 12 July 2021, accepted on 18 August 2021, published on 18 August 2021

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doi: 10.4108/eai.18-8-2021.170676

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1. Introduction

The advantages of the modular approach in the design of separation equipment include reducing the weight and dimensional characteristics of the equipment and combining several technological processes in one module. All this, in turn, simplifies the process of development and implementation of automated control systems and improves the quality of product preparation [1].

However, this design method requires significant preparatory measures [2]. Unification of equipment [3], selecting interchangeable modules, setting up their

interaction, and proper operation are the main problems in transitioning to a modular approach [4]. All these problems require the classification of separation equipment by design and technological features. Understanding classification, you can design modules of separation equipment, optimize their packaging, and coordinate.

Thus, the use of optimization packaging in the design of individual separation elements and equipment as a whole allows for simultaneously increasing basic operating parameters, efficiency, and intensity of separation. It also increases productivity to a new level, reducing separators' material consumption and capital and

operating costs when their production and oil transportation refining energy costs [5].

2. Literature Review

Using a modular approach in design and production becomes relevant due to the mass introduction of Industry 4.0 in production and various spheres of human life. The future output vision includes modular and efficient production systems and characterizes the scenarios in which products control their production process [6, 7].

The modular design approach to the modularity of devices aims to improve production, factories, and all the prerequisites [8].

The modular system is applied and widely studied in chemical production. Modular intensification of chemical processes is a growing trend in chemical engineering and can significantly improve chemical and production processes. Using a modular approach has advantages, including reduced energy consumption, cost savings, increased safety, and minimizing environmental impact. These benefits are key drivers and can accelerate the further development and application of modular intensification of chemical processes in the chemical, pharmaceutical industries, materials, pulp and paper, petroleum production, water treatment, and desalination [9].

There is also increasing differentiation and increasing product diversity [10]. There are two major development trends – a change in suppliers' market to buyers' market and a significant reduction in product life cycles [11, 12]. It leads to a rapid response of production to new products, which requires flexibility in output.

The plants' modular technology based on the device's original concepts can be a solution to overcome this obstacle [13]. Production in modular and flexible installations requires new types of devices. Traditional operations with units are limited due to their inherent geometric factors, a small range of scalability, and lack of flexibility and modularity [14]. Innovative concepts of scaling, modularity and transition from interrupted to continuous operation are essential conditions in distributors and separators [15, 16].

The use of modular systems implies that production can follow the market dynamics in time and space due to the rapid reconfiguration inherent in the modular units of such systems [17]. The time to market new products in response to immediate market requirements can be halved [18].

The advantages of the optimization techniques [19-22] can be used to design modular separation devices. Numerical modeling of hydrodynamics flow in phase separators was performed. The flow's hydrodynamic parameters were determined: the local velocity and density distribution and the free phase distribution surface height [23, 24]. Comparing the simulation results with the corresponding regulations and operating parameters confirmed the numerical experiment's reliability.

Simulation of a dynamic separation device for use in horizontal phase separators was also performed. The experimental model of coagulation by imposing vibrations was proposed in [25]. It was determined that applying the methods mentioned above in the design of individual separation elements and equipment simultaneously increases basic operating parameters and economic indicators for oil transportation and refining to a new level.

The modular approach to design has already been considered on extraction centrifuges, an excellent example illustrating the increased flexibility implemented in the process. Fast and efficient design and scaling processes are quickly implemented in operations on a technical scale [26].

The modular principle is also used for flexible, modular settling tanks for the separation of multiphase systems. Thus, system analysis is systematized to ensure the possibility of transfer to other multiphase systems for equipment design purposes.

Morphology for the definition and description of each modular structure in the technology industry and the degree of its transformation determination and a model of potential analysis for this purpose was developed by Wörsdörfer et al. [27, 28].

Despite some successful process intensification, the industry should overcome many obstacles to solve new issues for a continuous manufacturing approach [29–32]. The following existing research, analysis, and further research are carried out.

3. Literature Review

3.1 Implementation of a modular approach to the design of separation equipment

To ensure a modular approach in separation equipment design (Fig. 1), both theoretical and experimental studies of the developed modular separation devices were conducted. As a result, their hydrodynamic parameters and separation efficiency in each of them were determined. Various combinations of them were also considered, as well as methods of installation in the separation equipment. They were divided into the inlet, main, and outlet.

From the determined hydrodynamic parameters of the flow, a conclusion was made about their optimal layout. In this case, the distribution of velocity and pressure at the outlet of the separation elements and secondary processes can occur both during the primary process and at the apparatus's outlet in non-design modes, affecting the separation process in subsequent modules, were taken into account. Separation equipment in which it is most expedient to install each of the developed elements was also selected. The results of the analysis of the obtained data.



Figure 1. The separation equipment designed at the R&E Center for Industrial Engineering of Sumy State University

In this case, when designing the device, it is necessary to consider changing the package of existing modules to another, i.e., the possibility of practical disassembly and assembly of separators. For this purpose, it is necessary to exclude inseparable connections between the device and the frame of the package of modular separation elements.

Notably, the technological process of assembly-disassembly efficiency of separation equipment is ensured by developing special machine tools used to manufacture modular separation devices.

3.2 Design and technological classification of modular separation devices

The existing classification of modular separation devices (MSD) only by design features does not reflect technological aspects essential in designing and manufacturing modular separation devices and devices for their manufacture. Therefore, the new classification should consider both the design of MSD and assess the technical aspects of their production. Based on a comprehensive analysis of MSD and its main technological features, a design and technological classification which considers all possible designs of MSD is proposed.

By type of processing, MSD can be divided into three categories: MSD, most parts of which are subject to machining by cutting; MSD manufactured using Locksmith operations; MSD manufactured using additive technologies and did not require machining (Fig. 2).

MSD elements can be metallic, non-metallic, and combined [33-35], affecting cutting tools and cutting modes in machining MSD parts. According to the cross-sectional shape of the separation channels, MSD is divided into three categories: round parts, flat parts, and complex parts. This division allows choosing the type of technological equipment on which the processing of MSD parts will be performed

By weight, MSD is classified into light (less than 10 kg), medium (10–100 kg), and heavy (more than 100 kg), which also determines the choice of technological equipment on which machining will be performed. In terms of overall dimensions, MSD is divided into small (less than $100 \times 100 \times 100$ mm), medium ($100 \times 100 \times 100$ – $1000 \times 1000 \times 1000$ mm), and large (more than $1000 \times 1000 \times 1000$ mm), which determines the overall dimensions of machine tools, which produce parts of MSD.

Thus, the design and technological classification of MSD, which includes their production and technological features, has been developed. Based on this classification, it is possible to establish a structural code for selecting MSD for specific production needs and carry out the computer-aided design of technological processes to manufacture and assembly MSD parts into units based on MSD libraries. This approach can be used in information retrieval systems and reduce the design and technological preparation of production.

4. Results

As a result of modeling, primary and secondary processes of different nature accompanying the process of separation of multicomponent heterogeneous systems and intensifying the process of gas-family mixtures separation, several new separation and design methods of appropriate devices are proposed. A device for separating a dispersed liquid from a gas stream (Patent of Ukraine No. 102445) is provided. The device consists of a flowing element at the flow inlet into the casing and a stiffening ring at the casing flow outlet, which are interconnected by longitudinal blades attached to them in diameter at an angle. The blades on the flowing element are fixed rigidly, and on the stiffening ring – on the elastic elements, possibly bending the blades under the dynamic pressure. The device's application is separating dripping liquid from the gas stream in oil and gas, chemical, and other industries. An axial-tangential separation device is chosen as an analog to separate the liquid from a gas stream.

The device for the dispersed liquid separation from the gas flow in combination with all the essential features, including distinctive, allows to achieve a consistently high value of separation efficiency in conditions of sharp velocities and volumetric concentration of gas flow due to dynamic control of hydraulic resistance and flow velocity, as well as to prevent critical volumes of liquid from entering the separation equipment and accessing to the plug flow modes of operation.

The new method of highly dispersed droplet liquid captured from the gas-liquid stream, based on the latter's hydroaeroelastic interaction with deformable contact elements (Patent of Ukraine No. 130464), was also proposed (Fig. 3 a). This advanced method can be used in oil and gas, chemical, and other industries.

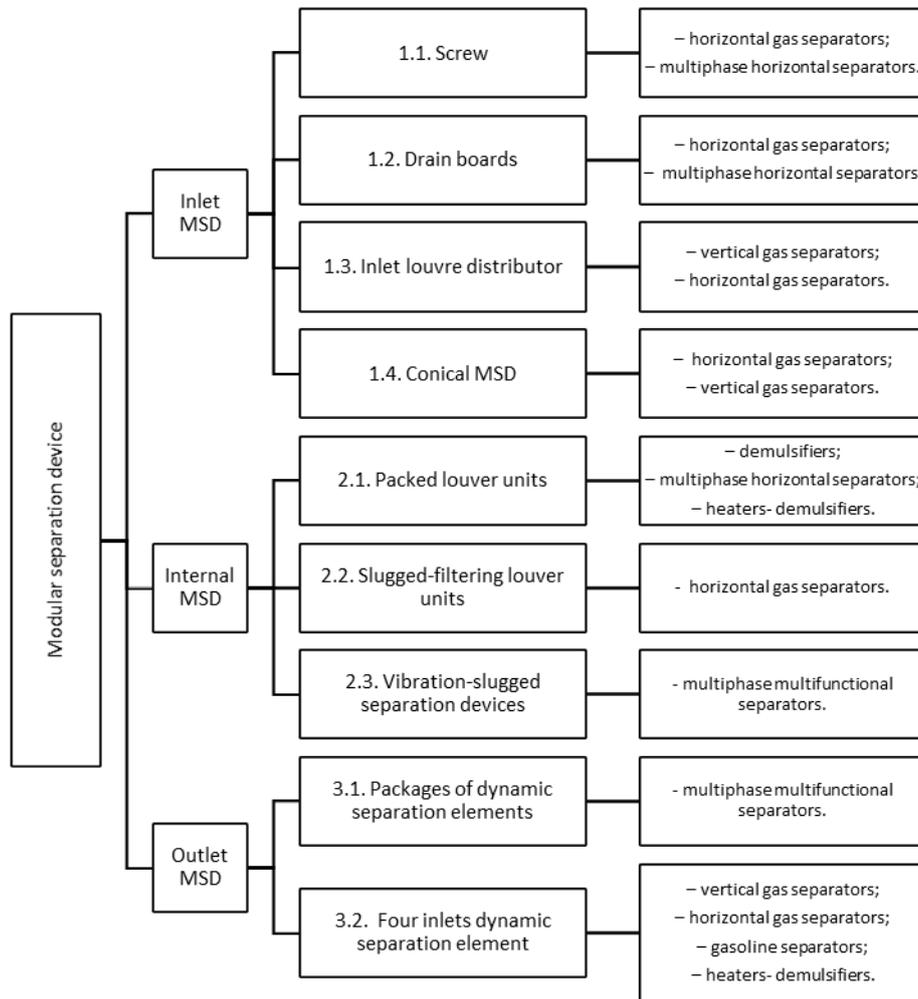


Figure 2. Characteristics of modular separation devices (MSD)

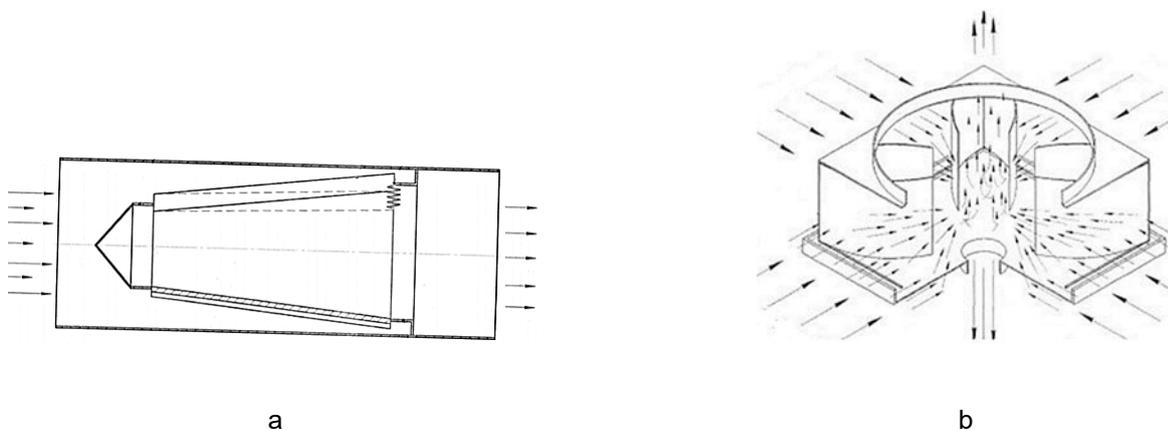


Figure 3. Design schemes for Patents of Ukraine No. 130464 (a), and No. 111039 (b)

Additionally, the highly dispersed droplet liquid captured from the gas-liquid stream in an advanced device for capturing the dispersed phase (Patent of Ukraine No. 111039) was proposed (Fig. 3 b). It includes the supply of gas-liquid flow into the separation package of plates, deviation of the trajectory of liquid droplets under inertia from the curved current line of gas-liquid flow enveloping the plates, deposition of droplets on the inner surface of the plates, their subsequent coagulation with liquid skinning, removing from separating zone skin of liquid flowing along the surface of the plates, characterized in that the supply of gas-liquid flow is

carried out in a separation package of plane-parallel beveled at an acute angle elastic plates cantilevered at an acute angle to the trajectory of gas-liquid flow with the possibility of bending parabolic half-cylinder under the action of dynamic pressure (velocity pressure) of the flow and internal stresses arising in the plates.

Also, the classification of modular separation devices, which allow receiving the structured code of the separation device depending on needs, was offered because of the research.

The design-and-technological classification of modular separation devices is presented in Fig. 4.

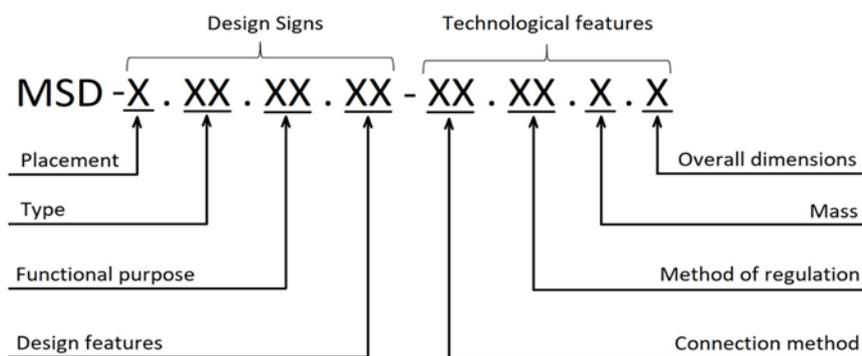


Figure 4. Design-and-technological classification of modular separation devices

Thus, an individual class of new separation methods and new designs of modular separation devices were proposed. Many proposed solutions, particularly vibration-filtering separation, dynamic regulation of gas-liquid flow rate, creating conditions for controlled gas-liquid flow pulsation, have no analogs in the world.

The designs mentioned above and methods are of great practical importance, particularly for the separation equipment design. In particular, they can be installed as independent separation elements, which are planned to be located along the direction of gas movement as an auxiliary stage of purification of associated petroleum gas in devices such as “Heater-Treater”, because these structures can solve the problem of reducing fluid mixtures to ensure the proper degree of purification of the gas supplied to the burners.

The proposed constructions and methods also have a practical application, in particular, in the optimization packaging of the gasoline separator of Hnidyntsi Gas Processing Plant [36], which has the form of a cylindrical vertical tank, where the baffle and overflow plates for gravitational-inertial separation of gas-liquid flow are located.

As far as light hydrocarbons in fine particles can be removed from the device with a gas stream, the discharge gas stream must be purified of the dispersed liquid. Therefore, the design of the gasoline separator provides for the net-shaped demister installation. However, the latter’s main disadvantage is insufficient gas stream purification from the dispersed liquid. On the other hand, liquid droplets pass through a mesh packing with the gas flow at a relatively low gas flow rate.

On the other hand, the liquid accumulates in the bumper with increasing gas velocity, and there is a re-introduction of the droplet liquid. Both cases significantly reduce the separation efficiency of the dispersed phase.

To prevent the above problem, a dynamic separation element, the original modular separation device designed to capture fine particles with abrupt changes in the hydrodynamic parameters of the flow, is installed. In this case, to increase the amount of separated gas instead of installed at the inlet of the device drainboards, where the extraction of the main amount of gas from the gas-liquid mixture is carried out, it is proposed to place a vertical screw element, which provides higher degassing efficiency due to additional application of stripping gas flow and much larger free phase distribution surface. In the vertical screw element, a significant increase in the surface area of the phase distribution is achieved due to its more compact placement, and due to the direction in the opposite direction to the flow direction of the gas-liquid stream of a separate gas stream, the intensity of the degassing process increases.

5. Conclusions

To meet global trends of high market volatility, reducing product life cycles, increasing customer needs, and reducing development and production cycles, the transition to flexible modular production plants is a crucial approach to meet these needs. However, for the manufacture and implementation of modular devices, a precise classification of devices is needed. The article

classifies modular separation devices according to their type, analyzes the design and technological features. As a result, the design and technological classification of modular separation devices was proposed.

As a result of experimental research, preliminary and acceptance tests of pilot (experimental) samples, the main hydrodynamic and separation characteristics of modular separation devices and combined multifunctional separators are determined: hydraulic resistance 0.15–2.00 kPa for units and 15–30 kPa for devices; effective capture of particles from the size of 5 μm ; efficiency of separate stages of separation (modular separation devices) – up to 70–90 %; efficiency of combined multifunctional separators – up to 99.5–99.9 %.

The offered multipurpose separators equipped with dynamically regulated modular separation devices do not concede to world analogs by the main technical characteristics, especially combined multistage separators “Sulzer AG” (Switzerland), “Shell Global Solution” (Netherlands), “Koch-Glitsch” (USA), “Monsanto Enviro-Chem Systems”, “ACS Industries” (USA); “Heater-Treater” devices of “NATCO” (USA), “Sivalls Inc.” Heater-Treater (USA), “EN-FAB Inc.” (USA); “Free Water Knock-Out (FWKO)” device manufactured by “Maloney Industries Inc.” (Canada).

Acknowledgments.

The achieved results were obtained to fulfill the objectives of the perspective development plan within the scientific direction “Technical Sciences” at Sumy State University within the related research project funded by the Ministry of Education and Science of Ukraine. The results have also been partially obtained within the research project “Creation of new granular materials for nuclear fuel and catalysts in the active hydrodynamic environment” (State Reg. No. 0120U102036) funded by the Ministry of Education and Science of Ukraine. This research was partially supported by R&E Center for Industrial Engineering (Sumy State University) and International Association for Technological Development and Innovations.

References

- [1] Skrynkovskyy RM, Yuzevych VM, Kataev AV, Pawlowski G, Protsiuk TB. Analysis of the methodology of constructing a production function using quality criteria. *Journal of Engineering Sciences*. 2019; 6(1): B1-B5.
- [2] Zaloga V, Yashyna T, Dynnyk O. Analysis of the theories for assessment of the quality management product efficiency. *Journal of Engineering Sciences*. 2018; 5(2): B1-B6.
- [3] Dynnyk O, Denysenko Y, Zaloga V, Ivchenko O, Yashyna T. Information support for the quality management system assessment of engineering enterprises. *Advances in Design, Simulation and Manufacturing II*. Proceedings of DSMIE-2019; June 11-14, 2019; Lutsk, Ukraine. Cham: Springer; 2020. pp. 65-74.
- [4] Yakovenko I, Permyakov A, Prihodko O, Basova Y, Ivanova M. Structural optimization of technological layout of modular machine tools. *Advanced Manufacturing Processes*. Proceedings of InterPartner-2019; September 10-13, 2019; Odessa, Ukraine. Cham: Springer; 2020. pp. 352-363.
- [5] Povstyanoy O, Zabolotnyi O, Slabkyi A, Dzyubinskyi A, Nykoliuk T. Development of new filtering materials for the purification of alternative fuels from mechanical impurities. *Advanced Manufacturing Processes*. Proceedings of the InterPartner-2019; September 10-13, 2019; Odessa, Ukraine. Cham: Springer; 2020. pp. 461-469.
- [6] Saniuk S, Saniuk A, Cagánová D. Cyber industry networks as an environment of the industry 4.0 implementation. *Wireless Networks*. 2021; 27:1649-1655.
- [7] Horňáková N, Jurík L, Hrablík Chovanová H, Cagánová D, Babčanová D (2019). AHP method application in selection of appropriate material handling equipment in selected industrial enterprise. *Wireless Networks*. 2021; 27:1683-1691.
- [8] Viero CF, Nunes FL. Module, modularity, modularization modular product: A theoretical analysis about the conceptual historical evolution. *Espacios*. 2016; 37(3):19.
- [9] Kim Y-H, Park LK, Yiacoumi S, Tsouris C. Modular chemical process intensification: A review. *Annual Review of Chemical and Biomolecular Engineering*. 2017; 8:359-380.
- [10] Buchholz S. Future manufacturing approaches in the chemical and pharmaceutical industry. *Chemical Engineering and Processing: Process Intensification*. 2010; 49(10):993-995.
- [11] Lier S, Paul S, Ferdinand D, Grünwald M. Modular process engineering: Development of apparatuses for transformable production systems. *Chemie-Ingenieur-Technik*. 2016; 88(10): 1444-1454.
- [12] Shah N. Process industry supply chains: Advances and challenges. *Computers and Chemical Engineering*. 2005; 29(6):1225-1235.
- [13] Riese J, Lier S, Paul S, Grünwald M. Flexibility options for absorption and distillation to adapt to raw material supply and product demand uncertainties: A review. *ChemEngineering*. 2019; 3(2): 1-18.
- [14] Seyfang BC, Klein A, Grützner T. Extraction centrifuges – intensified equipment facilitating modular and flexible plant concepts. *ChemEngineering*. 2019; 3(1):1-11.
- [15] Kiss AA, Lange J-P, Schuur B, Brillman DWF, van der Ham AGJ, Kersten SRA. Separation technology – Making a difference in biorefineries. *Biomass and Bioenergy*. 2016; 95: 296-309.
- [16] Lier S, Wörsdörfer D, Grünwald M. Transformable production concepts: Flexible, mobile, decentralized, modular, fast. *Chemie-Ingenieur-Technik*. 2015; 87(9):1147-1158.
- [17] Brodhagen A, Grünwald M, Kleiner M, Lier S. Increasing profitability by accelerated product- and process development with modular and scalable apparatuses. *Chemie-Ingenieur-Technik*. 2012; 84(5):624-632.
- [18] Müller D, Esche E, Pogrzeba T, Illner M, Leube F, Schomäcker R, Wozny G. Systematic phase separation analysis of surfactant-containing systems for multiphase settler design. *Industrial and Engineering Chemistry Research*. 2015; 54(12):3205-3217.
- [19] Janigová S, Schürger B. Design optimization of the modified planetary carrier. *Journal of Engineering Sciences*. 2021; 8(1):E17-E22.
- [20] Sokolov V, Porkuian O, Krol O, Stepanova O. Design calculation of automatic rotary motion electrohydraulic drive for technological equipment. *Advances in Design, Simulation and Manufacturing*. Proceedings of DSMIE-

- 2021; June 8-11, 2021; Lviv, Ukraine. Cham: Springer; 2021. pp. 133-142.
- [21] Tigariev V, Tonkonogyi V, Saliy V, Klimentko S, Dovhan A. Designing in modern CAD using information model. *Advanced Manufacturing Processes. Proceedings of the InterPartner-2019*; September 10-13, 2019; Odessa, Ukraine. Cham: Springer; 2020. pp. 331-341.
- [22] Krol O, Sokolov V. Parametric modeling of transverse layout for machine tool gearboxes. *Advances in Manufacturing II. Proceeding of MANUFACTURING 2019*; May 19-22, 2019; Poznan, Poland. Cham: Springer; 2019. Vol. 4, pp. 122-130.
- [23] Panchenko A, Voloshina A, Titova O, Panchenko I, Caldare A. Design of hydraulic mechatronic systems with specified output characteristics. *Advances in Design, Simulation and Manufacturing III. Proceedings of DSMIE-2020*; June 9-12, 2020; Kharkiv, Ukraine. Cham: Springer; 2020. pp. 42-51.
- [24] Bulgakov V, Pilipaka S, Adamchuk V, Olt J. Theory of motion of a material point along a plane curve with a constant pressure and velocity. *Agronomy Research*. 2014; 12(3):937-948.
- [25] Kameyama T, Niwa S, Park J, Matumura T, Sassa K, Asai S. The model experiment on coagulation of inclusions by imposing electroromagnetic vibration. *Tetsu-to-Hagane/Journal of the Iron and Steel Institute of Japan*. 2003; 89(6):623-628.
- [26] Mahringer D, Zerelli SS, Dippon U, Ruhl AS. Pilot scale hexavalent chromium removal with reduction, coagulation, filtration and biological iron oxidation. *Separation and Purification Technology*. 2020; 253:117478.
- [27] Wörsdörfer D, Lier S, Grünewald M. Potential analysis model for case specific quantification of the degree of eligibility of innovative production concepts in the process industry. *Chemical Engineering and Processing: Process Intensification*. 2016; 98:123-136.
- [28] Wörsdörfer D, Lier S, Grünewald M. Characterization model for innovative plant designs in the process industry-an application to transformable plants. *Chemical Engineering and Processing: Process Intensification*. 2016; 100:1-18.
- [29] Orlovský I, Hatala M, Janák M. Creation of simulation model of ceramic granulate production in spraying kiln. *Tehnicki Vjesnik*. 2010; 17(4):419-423.
- [30] Sokolov V, Krol O, Baturin Y. Dynamics research and automatic control of technological equipment with electrohydraulic drive. *Proceedings of RusAutoCon 2019*; September 8-14, 2019; Sochi, Russia. Sochi: IEEE; 2019.
- [31] Duplakova D, Teliskova M, Duplak J, Torok J, Hatala M, Steranka J, Radchenko S. Determination of optimal production process using scheduling and simulation software. *International Journal of Simulation Modelling*. 2018; 17(4):609-622.
- [32] Korohodskyi V, Kryshchtopa S, Migal V, Rogovyi A, Polivyanchuk A, Slyn'ko G, Manoyio V, Vasylenko O, Osetrov O. Determining the characteristics for the rational adjusting of an fuel-air mixture composition in a two-stroke engine with internal mixture formation. *East Eur J Enterp Technol*. 2020; 2(5-104):39-52.
- [33] Zabolotnyi O, Pasternak V, Ilchuk N, Cagáňová D, Hulchuk Y. Study of the porosity based on structurally inhomogeneous materials Al-Ti. *Advanced Manufacturing Processes. Proceedings of the InterPartner-2020*; September 8-11, 2020; Odessa, Ukraine. Cham: Springer; 2021. pp. 349-359.
- [34] Tarelnyk V, Martsynkovskyy V, Gaponova O, Konoplianchenko I, Dovzyk M, Tarelnyk N, Gorovoy S. New sulphiding method for steel and cast iron parts. *Proceeding of HERVICON+PUMPS 2017*; September 5-8, 2017; Sumy, Ukraine. IOP; 2017. Vol. 233(1): 012049.
- [35] Kolesnyk V, Kryvoruchko D, Hatala M, Mital D, Hutyrova Z, Duplak J, Alowa M. The effect of cutting temperature on carbide drilling life in the process of CFRP/Steel stacks drilling. *Manuf Technol*. 2015; 15(3):28-9.
- [36] Hu D, Wang Y, Ma C. Numerical simulation of supersonic separator with axial or tangential outlet in reflow channel. *Chemical Engineering and Processing: Process Intensification*. 2018; 124:109-121.