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## COMPLEX THERMODYNAMIC ANALYSIS OF THE HEAT-TECHNOLOGICAL COMPLEX OF SUGAR PRODUCTION: ANALYSIS METHOD

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The object of research is the heat-technological systems of sugar production and the heat-technological complex as a whole. A modern sugar factory is a complex hierarchical system of inextricably interconnected elements, and its basis – a heat-technological complex – combines the elements of technological, heat transfer, and mechanical equipment, in which complex physicochemical processes are simultaneously realized, closely interacting. Given the complexity of the internal relationships of processes, their parameters and characteristics, it is necessary to systematically approach the analysis of real functioning, performance evaluation and the solution of optimization problems of the complex as a whole, as well as its individual subsystems and elements.

In this work, it is proposed a method for thermodynamic analysis of the heat-technological complex of sugar production as a single thermodynamic system, which allows to analyze the main factors influencing the energy efficiency of the complex regardless of the course of processes implemented within the system. The methodology is based on a joint analysis of the general synthetic and analytical balances of mass, energy and entropy. This model has a deep physical foundation, because the material balance equation is an integral form of the law of conservation of the quantity of matter, the energy balance equation is an integral form of the first law of thermodynamics, and the entropy balance equation is an integral form of the second law of thermodynamics. The main objective of the methodology is a quick assessment of the excellence of the heat-technological complex and its definition of «energy-saving potential». Also, the application of the principle of energy compensation of irreversibility and entropy criteria allows to determine the sources and causes of system imperfections, and imperfections are compiled to help develop a system of measures to increase the efficiency of the optimal sequence complex. Therefore, the proposed methodology of thermodynamic analysis, in contrast to the methods based on exergy characteristics, provides a comprehensive analysis, operating only with the fundamental laws and principles of classical thermodynamics. It can also be used both to optimize the energy characteristics of existing ones and to design new sugar industry enterprises.

**Keywords:** energy efficiency, irreversibility of processes, thermodynamic analysis, entropy method, resource-saving measures.

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# REPORTS ON RESEARCH PROJECTS

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## ASSESSMENT OF THE AUTHENTICITY OF A SEMIEMPIRICAL TURBULENT COMBUSTION METHOD IN AFTERBURNER OF A GAS TURBINE ENGINE

page 12–15

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The object of research is the working process of the afterburner of the combustion chamber of a turbojet dual-circuit engine with flow mixing. The research was aimed at developing a comprehensive methodology for calculating the afterburner-output device of a forced turbojet engine, taking into account the unevenness of the coefficient of oxygen excess and flow turbulence.

To calculate the process of mixture formation, let's use the model of the separate flow of the gas and liquid phases, taking into account the influence of finite transfer rates between the phases. The gas phase is calculated using a numerical method based on the Eulerian-Lagrangian approach, which allows one to calculate a three-dimensional compressible unsteady flow in an afterburner and is described by Navier-Stokes equations with Reynolds averaging and a one-parameter model of turbulent viscosity. The differential equations of the liquid phase are solved by the Runge-Kutta method. Accounting for turbulent combustion is carried out using the semi-empirical theory.

The main indicator of the afterburner combustion chamber working process is the coefficient of completeness of combustion, on which the engine thrust during forced operation depends. To evaluate the combustion efficiency, the fields of velocity, temperature, pressure, mass fraction of oxygen, fuel vapor and pulsation velocity are calculated. These values are determined by numerical simulation of a two-phase flow. The work uses a model of the separate flow of the gas and liquid phases, taking into account the influence of finite transfer rates between the phases. Having data of numerical calculation and a semi-empirical model, let's determine the completeness of fuel combustion, depending on the coefficient of excess air and the length of the combustion zone. The technique used in this work allows to calculate the completeness of fuel combustion in the afterburner, and the calculation results coincide with experimental data with an error of no more than 7 %. Having data on the completeness of combustion, one can determine the thrust of the nozzle during forced operation of the engine.

**Keywords:** gas-dynamic calculations, aircraft engines, turbojet engines, afterburner and output device, work process.

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## RESEARCH OF NONLINEAR DYNAMIC DEFORMATION OF SPATIAL BODIES WITH CRACKS

page 16–18

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The object of research is the process of dynamic interaction of a complex system of cyclically symmetric parts of the support joint, taking into account the presence of stationary cracks. A significant number of structural elements and parts operated under dynamic loads are characterized by the occurrence and propagation of cracks in areas of significant plastic deformation. In particular, for the supporting device, it is a cyclically symmetric body with a limiting case of heterogeneity, under the action of pulsed loads, plastic flow zones arise at the boundaries of the joints of the cylindrical part with projections. If there are cracks in these areas, it becomes necessary to reliably determine the fracture parameters and predict the crack growth over time.

To build models of this class of objects, one of the most universal and reliable numerical methods is the semi-analytical finite element method.

In this paper, the results of calculating of the parameters of fracture mechanics on the basis of the semi-analytical method of finite elements are presented for an object with inhomogeneous physical and mechanical properties in the presence of stationary cracks under conditions of pulsed loading and plastic deformations. The numerical study is performed in two stages. At the first stage, the laws of the elastic-plastic dynamic deformation of the system are established. The most probable zones of damage accumulation and cracking are determined, which is the reason for the failure of structural elements. At the second stage, a model with a crack located in the zone of plastic deformations is considered, the calculated values of the dynamic stress intensity factors are studied, and their evolution over time is investigated.

The obtained research results can be used in numerous calculations of inhomogeneous bodies with damage such as cracks in the conditions of elastic-plastic dynamic deformations.

**Keywords:** dynamic load, finite element model, stationary cracks, fracture mechanics parameters.

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## DETERMINATION OF GEOMETRIC AND KINEMATIC CHARACTERISTICS OF FDM 3D PRINT PROCESS

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The process of applying a polymer thermoplastic material in the 3D printing process using the FDM technology (Fused Deposition Modeling) was investigated. The object of study was the discrete layer of the prototype. To determine the geometric parameters, samples were made with a thickness of one nozzle diameter (0.5 mm) of the print head of a 3D printer. The obtained samples were cut into sections of the same width (10 mm), in each section a separate layer of the deposited material was cut off. This made it possible to determine the change in thickness from the initial to the final point of the layer. It turned out that the layer thickness is less than the diameter of the nozzle at the beginning of the movement of the print head, gradually grows and at a certain stage begins to exceed the diameter of the nozzle. The obtained values were from 0.4 to 0.6 mm for a nozzle with a diameter of 0.5 mm. The reason is that at the beginning of the supply of the consumable material there is a highly elastic delay in the reaction of the polymeric material to the pressure in the print head and for a certain period of time this part of the material is not applied to the sample, and then the polymer melt swells. Moreover, with an increase in the nozzle diameter, the effect of these phenomena also increases. Also, the printing process was recorded on a wide-format camera in HD-quality with a frequency of 50 frames/s, which allowed to study the dynamics of the application of consumable polymer thermoplastic material. The results showed a difference in speeds from those specified in the executive code. Moreover, for different designs of kinematic schemes for moving the print head, the deviations of the parameters were different – real values were more than theoretical (set) by 20–50 %, depending on the type of FDM 3D printer. This is due to the difference in the inertial characteristics of the various structures of the kinematic patterns of movement of the print head. The results are the basis for further more detailed study of the influence of the configuration of the forming organs and the design of FDM 3D printers on the spatial printing process.

**Keywords:** 3D printing, 3D printer, Fused Deposition Modeling, polymer thermoplastic material, print head, kinematic scheme.

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## RESEARCH OF TEMPERATURE CHANGE OF PAVEMENT HEATING IN THE PROCESS OF HOT IN-PLACE RECYCLING OF ASPHALT CONCRETE

page 22–24

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The object of research is the technology of hot asphalt concrete regeneration by the in-place method. Temperature regimes for heating asphalt concrete pavement are one of the key technological parameters that affect the quality of the output regenerated asphalt concrete. In order to establish the dependence of the temperature of the pavement heating at different depths on the heating time, field studies are carried out directly when performing work on the hot regeneration of asphalt concrete using the Reshape method. The work is carried out at an ambient temperature of 25–30 °C and calm weather. The regenerated hot asphalt mix, which is used when conducting studies on the grain composition and bitumen content, corresponded to a hot, fine-grained mixture, dense asphalt concrete, type A, continuous granulometry, grade II, in accordance with DSTU B V.2.7-119:2011. Content of residual bitumen loosened asphalt crumb is 6.0 %. During the research, measurements are carried out at different speeds (1.8 m/min and 2.1 m/min) of the thermal installation for heating the Wirt-

gen HM 4500 asphalt concrete pavement (country of origin is Germany). The obtained graphical dependencies and mathematical models make it possible to determine that the most optimal pavement heating mode is gradual heating. This mode will allow avoiding the burning of bitumen and provide pavement heating at the level of the base of the regenerated layer, which is very important when determining the temperature of mixing the mixture. Analysis of graphs and mathematical models suggests that a decrease in the temperature of the pavement heating by at least 10–20 °C will lead to an increase in the performance of the thermal device. In this case, the increase in productivity can be from 20 % to 25 %, which will reduce the gas consumption and, accordingly, the cost of work. Thus, the obtained dependencies can be used to optimize the process of hot asphalt concrete regeneration by the in-place method.

**Keywords:** asphalt concrete regeneration, automobile road, asphalt concrete pavement, hot recycling, current repair, economic efficiency.

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## EVALUATION OF THE SURFACE ENERGY OF DISPERSED ALUMINIUM OXIDE USING OWENS-WENDT THEORY

page 25–27

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Knowing the value of the surface energy of powder materials allows to predict the interaction of the solid phase with liquids, the formation of stable dispersions, durable and resistant to aggressive factors of composites. The application of the Owens-Wendt model for determining the change in the surface energy of aluminium oxide modified by various water repellents is considered. Also, to determine the contact angle of the surface of the modified material, the Washburn method is used, which consists in determining the rate of capillary rise of the test fluid. This method is chosen due to low requirements in the accuracy of measuring equipment and at the same time shows a high degree of accuracy of the results.

The object of research is a method for determining the surface energy of powder materials, using aluminium oxide modified with polymethylhydrosiloxane as an example. Surface modifications of the aluminium oxide powder are carried out in a xylene suspension.

In the work, the determination of surface energy is carried out in accordance with the Owens-Wendt theory by the graphical method in accordance with the obtained values of the contact angle of the material according to the Washburn method. It is established the shape of the particles of aluminium oxide and their average size, and also calculated the specific surface of the material. A modifier, polymethylhydrosiloxane, is found, with the help of which it is possible to obtain a stable superhydrophobic state, and the optimal concentration by determining the contact angles of the powder material with test liquids according to the method proposed by Washburn.

To increase the accuracy of determining the surface energy of the material according to the Washburn method, a mixture of water with ethanol is used, and the components of surface tension are calculated. It is shown that the values of the contact angle of the surface of the dispersed material obtained using a mixture as a test liquid can be used to calculate the values of the components of the surface energy of aluminium oxide. In this case, there is a lack of error in the form of the Cassie state, which is observed for hydrophobic dispersed materials when using water as a test fluid.

**Keywords:** aluminium oxide, Owens-Wendt model, Washburn method, surface energy, surface tension.

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## RESEARCH OF THE WEAR RESISTANCE OF MULTI-COMPONENT BRONZE IN THE CONDITIONS OF THE HYDRAULIC OIL PROCESSED BY THE POWER FIELD

page 28–31

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The object of research is the process of changing the wear resistance of bronze under the conditions of electrostatic treatment of hydraulic oil. The wear resistance of the bronze elements of the friction pairs determines the life of the axial-plunger pumps and affects their «feed – pressure» main characteristics.

The studies were based on the theory of experimental design and statistical methods for processing test results. The research methodology provided for modeling the process of sliding friction using a «block – roller» friction pair on the SMC-2 friction machine (the country is the manufacturer of the USSR, modernization in Ukraine). This type of friction takes place in the «plunger – cylinder block», «distribution disk – cylinder block» tribosystem. Also, the method was supposed to pre-treat the hydraulic oil with an electrostatic field in the device, followed by feeding it into the tank with a roller using a pump station. Two independent factors varied: electrostatic field strength and hydraulic oil operating time. The constant factors were the hydraulic oil flow rate in the device, hydraulic oil temperature, contact pressure, linear roller sliding speed and time of each test.

The obtained experimental data made it possible to establish a regularity characterizing the sliding friction process when a force field is applied to hydraulic oil. This pattern reveals the effect of electrostatic field strength and hydraulic oil operation on the wear resistance of a bronze block, which was tested on a friction machine SMC-2. This made it possible to determine the rational values of the parameters of the electrostatic field, at which the maximum wear resistance of the bronze is achieved depending on the operating time of the hydraulic oil, ranging from $1 \cdot 10^6$ V/m to $1.25 \cdot 10^6$ V/m. Thus, the effect of the field on oil helps to increase the wear resistance of bronze up to 5 times in the conditions of hydraulic oil in the delivery state and up to 3 times in oil with an operating time of 2000 hours. The influence of the field leads to polarization effects in the oil, which contribute to the formation of quasicrystalline films on the friction surface, increasing the tribojunction wear resistance.

**Keywords:** hydraulic oil, electrostatic field, wear resistance of bronze, tribological preparation, friction pair, roller block.

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## NUMERICAL SIMULATION OF THE OUTFLOW OF TWO PHASE FLOW FROM DETONATION UNIT BARREL

page 32–37

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The object of research is the application of detonation coatings using cheap and safe energy sources without reducing the quality characteristics of the coatings. One of the significant drawbacks of the detonation-gas method, from the point of view of safety and cost, is the widespread use of acetylene-oxygen mixtures. To some extent, the use of propane-butane mixtures solves the problem, however, the energy parameters of the process are reduced, which leads to the search for a compromise solution – methylacetylene-allene fraction (MAF). This energy carrier occupies an intermediate position in terms of energy characteristics and at the same time is stable and safe. The use of various energy carriers requires detailed information on the dynamics of the behavior of detonation products and sprayed particles in the barrel of a detonation unit. In the course of research, the problem of the development of deflagration combustion, the transition to detonation inside the unit's technological channel and the movement of the detonation and shock wave front based on the Navier-Stokes equations with a two-layer Menter's turbulence model is solved. To calculate multiphase flows, a volume of fluid model (VOF) is used, which assumes that two liquids (or phases) or more do not mix and do not penetrate each other. The results of numerical modeling of the process of expiration of detonation products from the barrel of a detonation unit, as well as the heat exchange process between combustion products and powder particles, are presented. The velocities and temperatures of alumina particles are determined for various ratios of MAF/oxygen at the outlet of the process channel and in front of the substrate. The results of numerical modeling are compared with experimental data. It is shown that the model used adequately describes the heat transfer process. As a result of the studies, it is justified to use MAF as an energy carrier without reducing the quality of coatings of oxide ceramics. The developed mathematical model is suitable for modeling the process from any combination of gas components capable of detonating.

**Keywords:** detonation spraying, thermal spray coatings, heat transfer in a two-phase flow, mathematical modeling of detonation processes.

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## ANALYSIS OF STRENGTH AND DEFORMATIVITY OF GLASS PLATE JOINTS UNDER STATIC LOADING

page 38–41

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The weak point of any structure is always the elements junction node. This article presents the results of a study of the adhesion of glass plates interconnected over the entire surface by means of adhesive materials and triplex technology under the action of static loading. The bearing capacity and deformability of such joints was established. For the research purposes there were designed, manufactured and tested 6 series of prototypes. Thus, the object of the study is 6 series of test specimens for testing the adhesion of glass plates to each other. The prototypes consisted of three glass plates, each 10 mm thick, interconnected by means of triplex technology and various adhesive materials. Before bonding, the glass plates of the prototypes of I–V series were cleaned of dirt and degreased. The adhesive was applied to the entire surface of one plate. Then, the glass plates were firmly interconnected with the help of the vise and held for 5–10 minutes. The curing time depended on the adhesive materials. The curing of the glue of the prototypes of the fourth and fifth series was done under the rays of an ultraviolet lamp. The plates of the sixth series prototypes were interconnected by triplex technology, where EVASAFE polymer film (Bridgestone, Japan) was inserted between the plates and the prototypes were heated to 130 °C and held for 30 minutes.

An experimental research program was developed. The test rig consisted of a stand for static structural strength tests. The external load $N$ was applied by means of a hydraulic jack and was performed step by step. The magnitude of the load was 1.0 kN and was monitored using dynamometer for the I–V series prototypes and a ring dynamometer for the VI series prototypes until the complete destruction of the prototype. At each load stage a 10 minutes exposure was performed followed by gauge reading.

On the basis of the obtained results, an analysis of glass plates adhesion was performed and an averaged dependency graph of shear deformations and tangent stresses $\tau=N/A$ for the series of the prototypes was constructed. This provides the ability to obtain strengths and deformations for a series of prototypes.

**Keywords:** glass layers, triplex, prototype, glass plates, elements junction node.

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## DEVELOPMENT OF A MATHEMATICAL MODEL OF MEASURING CONTROL DEVICE OF NATURAL GAS HUMIDITY

page 42–45

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The object of research is the measuring control of the humidity of natural gas. There are many methods and devises of determining humidity that are used in laboratory measurements under normal conditions. However, in practice, it is necessary to measure humidity over a wide range of pressure and temperature, as well as at high and medium pressure in the gas pipeline. Such use requires the development of sensors that are reliable, stable and resistant to contamination and high pressures. Due to their simple, reliable design and rather high accuracy of measurement, humidity meters based on the use of the microwave method have been widely used.

Based on the studies, a devise for measuring the humidity of natural gas is proposed on the basis of a microwave method for measuring humidity, in which, unlike the known methods, the use of a traveling wave in a waveguide is proposed. And changes in the dielectric properties of gases during their interaction with microwave waves are estimated. Studies have been carried out that showed that the presence of a comparative channel made it possible to increase the measurement accuracy, since a two-channel system, unlike a single-channel system, eliminates the instability of the value of the input signal supplied by the generator.

The principle of operation of measuring control device of natural gas humidity is described, which contains a microwave generator, attenuators, waveguide tees, a waveguide comparison section, a temperature and pressure sensor, switches for comparative and measuring channels, a measuring cell, amplifier, processor, indicator.

A mathematical model of the measuring control device of natural gas humidity has been developed, which takes into account the value of the dielectric constant of the gas of the measuring and reference channels, and contains temperature correction coefficients, the use of which allows to increase the accuracy of humidity measurement.

The research results allow to argue about the prospects for the practical application of measuring the natural gas humidity based on the microwave traveling wave method.

**Keywords:** microwave method, traveling wave, mathematical model, measuring control device of natural gas humidity.

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## CIRCUIT DESIGN OF BUCK-VOLTAGE CONVERTER WITH DIGITAL CONTROL SYSTEM

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The objects of research are processes in electrical scheme and enormous digital control systems in converter. One of the most problematic things is transfer and energy change in converter for current and voltage in order to reach certain value of digital range with a minimal percentage of error.

This work explores buck-voltage converter with digital control system. An enormous considered procedure of projecting electrical scheme. There was described electrical scheme with a control system, which, thanks to the digital system, provides dates with more accuracy in the output of converter, among them: assignment of certain digital range of output voltage and system's impact on working scheme.

During the research there was used selection of hardware features and software tools, accepting peripheral devices, which let quickly and simply set up microcontroller for certain operating mode and to realize controlling system for buck converter in a programmatic manner.

There was analyzed procedure of solving and choosing of the certain parts of electrical scheme, where was used to construct:

– microcontroller for receiving, processing and issuance of information in electrical scheme;

– driver operating and analog-to-digital conversion;
– driver for control of the switches – basically transistors;
– components of the buck-converter circuit.

There is description and schematic choice of the certain parts of the scheme. There was included switch, capacitor and diode for buck converter; certain range of the frequency and voltage for microcontroller; control of the power keys of the circuit with the corresponding operating parameters for driver.

There was received a system, which in prospect will become a basis to step down voltage value to the certain level. This is because defined method has a set of features, particularly digital regulation system with a discrete step and analog-to-digital converter in the capacity of feedback. Therewith provides possibility for receiving more accuracy value. In comparison with analogic buck converters, this converter has voltage parameter with fractional error.

**Keywords:** buck-converter, signal control, galvanic isolation in power equipment, digital control.

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