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The Solution of Private Problems of Optimization for Engineering Systems of Buildings

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Abstract: The relevance of the topic due to the decision of problems of the economy of resources in heating systems of buildings. To solve this problem, we have developed an integrated method of research which allows solving tasks on optimization of parameters of heat exchangers vehicles. This method decides multi-criteria optimization problem with the program nonlinear optimization on the basis of software with the introduction of an array of temperatures obtained using thermography. The researcher have developed a mathematical model of process of heat exchange in heat exchange surfaces of apparatuses with the solution of multicriteria optimization problem and check its adequacy to the experimental stand in the visualization of thermal fields an optimal range of managed parameters influencing the process of heat exchange with minimal metal consumption and the maximum heat output fin heat exchanger, the regularities of heat exchange process with getting generalizing dependencies distribution of temperature on the heat-release surface of the heat exchanger vehicles, defined convergence of the results of research in the calculation on the basis of theoretical dependencies and solving mathematical model.

Key words: Mathematical model, heat exchanger, air heating systems of buildings, ribbed surface, thermal imaging survey, minimal

INTRODUCTION

The current trend in reduction in energy use in buildings is oriented towards sustainable measures and techniques aimed to energy need restraint. Even so, studies have underlined large differences in energy consumption in similar buildings, suggesting strong influence of occupant behavior. Nevertheless, it is worth noting a lack of knowledge and study of the parameters influencing heat exchange in buildings. Existing dynamic energy simulation tools exceed the static size of the simplified methods through a better and more accurate prediction of energy use, however, they are still unable to replicate the actual dynamics that govern energy uses within buildings. The pursuit of a comfort condition in indoor environment is a result of complex correlation between different parameters that have to be optimized. As a consequence a need for always more accurate statistical models, considering different behavioural patterns and preferences among indoor environmental quality is arising.

Air heating systems are regarded as energy efficient and comfortable heating systems, so that, they have been extensively used in residential and non-residential buildings. Many energy efficient building technologies involving increased thermal insulation and air tightness have been applied in the heating buildings. Combined heat transfer consists of thermal conduction, convection and radiation which exist on building inner surface temperature and air temperature that are coupled through each other.

Nowadays, the trade-off among comfort, health and energy consumption in deciding indoor design parameters of air heating becomes more and more concerned. In the large space buildings with stratified air heating, human comfort becomes extremely important. It directly depends on the parameters and characteristics of heat exchangers used in engineering constructions.

A heat exchanger is a device to transfer thermal energy between two or more fluids, one comparatively hot and the other comparatively cold. Heat exchangers are used in a wide variety of applications such as power production, process, chemical and food industries, electronics, environmental engineering, waste heat recovery, manufacturing industry, air-conditioning, refrigeration and space applications.

In the thermal design of heat exchangers two of the most important problems involve rating and sizing. Determination of heat transfer and pressure drop is referred to as a rating problem. Determination of a physical size such as length, width, height and surface areas on each side is referred to as a sizing problem.

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Air heating systems of buildings are resource-consuming systems for this reason, improving their resource efficiency appears to be of great significance. Heating of air is provided by heat exchangers which have been studied quite thoroughly. The studies involved different authors to deal with particular aspects of improving heat exchange elements (Yu and Xie, 2012; Shafeie *et al*., 2013; Bejan, 2013).

A special and important class of heat exchangers is used to achieve a very large heat transfer area per volume. Termed compact heat exchangers these devices have dense arrays of finned tubes or plates and are typically used when at least one of the fluids is a gas and is hence characterized by a small convection coefficient. Plate heat exchangers, finned-tube heat exchangers and plate-fin heat exchangers are in the class of compact heat exchangers (Jaszkiewicz, 2001; Liu and Sakr, 2013).

The basic problems that researchers face with while selecting from various available types of heat exchangers are the following. The heat exchanger must satisfy the process specifications. It must be able to function properly to the next scheduled shut down of the plant for maintenance (Lasdon and Waren, 2000).

The heat exchanger must withstand the service conditions of the environment. It must also resist corrosion by the process and service streams as well as the environment. The heat exchanger should also resist fouling (Egorov *et al*., 2006; Burke *et al*., 2003). Additionally, the exchanger must be maintainable which usually implies choosing a configuration that permits cleaning and the replacement of any components that may be especially vulnerable to corrosion, erosion or vibration. This requirement will dictate the positioning of the exchanger and the space requirement around it (Egorov *et al*., 2006).

What is quite important is that the heat exchanger should be cost effective. The installed operating and maintenance costs including the loss of production due to exchanger unavailability, must be calculated and the exchanger should cost as little as possible.

As it is mentioned by Yu and Xie (2012), there are definite limitations on exchanger diameter, length, weight and tube configurations due to site requirements, lifting and servicing capabilities or inventory considerations.

The rating problem in heat exchange is concerned with the determination of the heat transfer rate and the fluid outlet temperatures for prescribed fluid flow rates, inlet temperatures and allowable pressure drop for an existing heat exchanger. So, the heat transfer surface area and the flow passage dimensions are critical (Himmelblau, 1972). The sizing problem, on the other hand, involves determination of the dimensions of the heat exchanger, that is selecting an appropriate heat exchanger type and determining the size to meet the requirements of specified hot-and cold-fluid inlet and outlet temperatures, flow rates and pressure drops (Egorov *et al*., 2006).

The main properties of heat exchangers such as amount of heat exchange, area of heat exchange, metal capacity and cost of an apparatus depend largely on the size of ribbing, so the efficiency of the design is determined by the optimal height of the rib (Burke *et al*., 2003; Liu and Sakr, 2013; Hasan *et al*., 2012).

One of the researcher of this study, Khrustalev and Nesenchuk (2007) looked into the criterion to assess the efficiency of heat exchanger design. The study also suggests theoretical dependencies to calculate technical characteristics of heat exchangers. However, these dependencies do not allow optimization on several parametres.

Melekhin and Melekhin (2014) in his previous studies studied the multi-criterion optimization of the rib in heat exchangers based on two criteria, however other parametres were not considered. Therefore, the problem of optimization of heat exchanger's parameters is still unsolved and has a great practical importance for industry. The conduct of practical studies to optimize basic parametres in engineering systems of buildings is urged by power-saving requirements (Khaled and Vafai, 2011). The given practical problem of improving engineering systems is to optimize the design of the heat exchanger in air heating systems of buildings. The novelty of the given study lies in the following:

- We have elaborated a new complex research technique, based on multi-criterion problems with generic dependencies, obtained from empirical data
- We have obtained functional dependence of process parametres on heat exchanging surfaces on optimal geometrical parametres of the heat exchanger

The practical value of the paper is in the following:

- We have derived semi-empirical equations for computing and designing air heating systems in buildings
- We have reduced metal capacity of heat exchangers which are used in air heating systems of buildings

MATERIALS AND METHODS

In order to set optimal parametres for the heat exchanger and balance its design with technological elements the author conducted actual studies with the help of the complex method. It comprises optimization of parametres for heat exchanging process based on multi-criterion multi-parameter mathematical models and experiments with thermal fields visualization (Fig. 1).

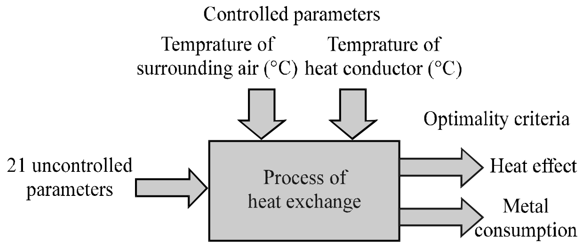

Fig. 1: Model of the process of heat exchange

The optimization problems are solved using the method of non-linear optimization in computing complex IOZO NM 3.0b (Egorov *et al*., 2006).

Besides, the solution of such problems is also possible with the help of non-linear optimization program Generalized Reduced Gradient (GRG2), designed by Leon Lasdon, University of Texas at Austinand Allan Waren, Cleveland State University and based on the method of conjugate gradients-iterative method for unconstrained optimization in multidimensional space. The main advantage of this software package is that it is able to solve the quadric optimization problem within finite number of moves. So, first the author describes the method of conjugate gradients to optimize the quadric functional then he derives iterative formulas and estimates convergence rate. Next, the author demonstrates, how the method of conjugate gradients is generalized to optimize arbitrary functional, looks at different variations of the method, assesses convergence. The shortcoming is that controllable and non-controllable parametres and criteria are constrained (Lasdon and Waren, 2000).

It is possible to use as a mathematical model a two-criterion problem of clusterization with fuzzy constraints. The fuzzy constraints can be set by specific preference functions. The solution is made in Boolean variables with the help ofstochastic search, improved by heuristics. The algorithm is implemented in the form of a universal software module (Jaszkiewicz, 2001; Burke *et al*., 2003).

Solution of multi-criterion multi-parameter non-linear optimization problem of engineering systems in buildings suggested applying software package IOSO NM Version 3.0b where the researcher entered empirical data from thermal imaging. A special feature of this software is its compatibility with microsoft excel and other programs. IOSO package allows setting controllable and non-controllable parameters, optimal criteria and constraints for the process. Further, IOSO program establishes optimal process parameters by using the data from excel.

Preliminary IOSO procedure is forming the initial experiment plan which can be passive (using the previously obtained information about variable parameters, optimization criteria and constraints) as well as active when the set is generated in the initial search field in accordance with the preset partition law. Each vector of variable parameters for optimization and constraints implies direct use of mathematical model of the object studied. The number of points in the initial experiment plan depends on the problem dimension and the chosen variant of approximation function.

RESULTS AND DISCUSSION

In the given study, the researchers makes a thermodynamic analysis and optimizes heat exchangers of air-cooling at the same time these improvements are not based on the complex approach (Salimpour and Bahrami, 2011). The occurrence of new methods, namely a complex method, allows combining mathematical modeling with visualization of heat fields and as a result obtaining optimal parametres of heat exchangers for the given systems (Melekhin and Melekhin, 2014). The purpose of the given study is improving the efficiency of heat exchangers by optimizing their parametres and design. To achieve this goal we set and solved the following tasks:

- We have developed a mathematical model of multi-criterion problem to optimize heat exchange on the ribbed heat exchanging surfaces
- Using the mathematical model we developed we have determined the mechanism of heat exchanging process and have derived dependencies of temperature distribution on heat exchange surfaces in heating systems of buildings during the heating season
- We have made a comparison of the obtained results with the results based on the established theoretical dependencies
- We have reduced the metal capacity of the heat exchanger by improving its heat engineering characteristics

To find the minimum mass of the ribs of the heat-exchange apparatus with the maximum of its heat productivity developed mathematical model of multi-criteria optimization problem parameters heat-giving elements of the heat-exchange apparatus systems of air heating of buildings which is solved using the method of nonlinear optimization (Kashevarova and Permyakova, 2007; Kashevarova and Martirosyan, 2013).

Formulation of the mathematical model has been made for the outer surface of the radial ribs (Fig. 2). The temperature on the surface of the ribs defines heat output

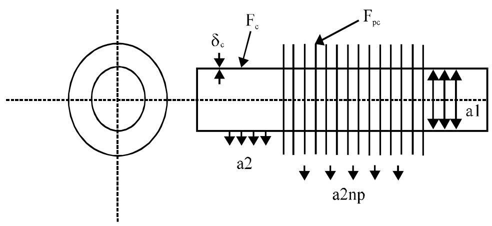

Fig. 2: Radial edge

and the height of the rib-metal heat-exchange apparatus, so as the optimality criteria for staging a mathematical model selected (Lapidus, 1977):

- The temperature on the surface of the ribs (J_1)
- The height of the ribs (J_2)

As unmanaged parameters taken: the radius of the carrier pipe of a thickness of edges, the thermal conductivity of the ribs, the location of the beam in a heat exchanger, step ribs, the number of ribs, the number of the Nusselt number for the air, the Reynolds number for the air, the coefficient of heat transfer from the wall to the air, etc. (x_1, ..., x_n).

In research the estimation of influence of these parameters on the process of heat exchanger. As of controlled parameters are: ambient air temperature, the temperature of the heat-carrier (U_1, ..., U_n) as the most influence on the heat transfer process.

In the process of heat exchange occurs between the warm water and the environment which depend on parameters of water and air. Parameters that characterize these changes are within the permissible limits, established for the process.

The dependence of optimization criteria (Sobol and Statnikov, 1981) and process parameters can be represented in the following form:

$$\begin{aligned} J_1 &= J_1(x_1, ..., x_n, U_1, ..., U_n) \rightarrow \max \\ J_2 &= (x_1, ..., x_n, U_1, ..., U_n) \rightarrow \min \end{aligned} \qquad (1)$$

Restrictions on the parameters of the process is within the following limits:

$$\begin{aligned} x_i^{min} &\leq x \leq x_i^{max} \\ U_i^{min} &\leq U \leq U_i^{max} \\ J_i^{min} &\leq J_i(x_i) \leq J_i^{max} \end{aligned} \qquad (2)$$

The task of searching for the optimal height of the ribs is to find x∊D in cases when:

$$\begin{aligned} J_1(x_1, ..., x_n, U_1, ..., U_n) &\rightarrow \max \\ J_2(x_1, ..., x_n, U_1, ..., U_n) &\rightarrow \min \end{aligned} \qquad (3)$$

Thus, the problem can be formulated in the following way: it is required to find such managed parameters element of heat exchanger (the height of the edges) which are optimal from the point of view you are the chosen criteria under certain constraints.

The basis of mathematical model based on Bessel equation describing the distribution of temperature on the outer surface of the ribs (Khrustalev and Nesenchuk, 2007).

For the staging of the mathematical model are determined boundary conditions of the process of heat transfer in the research of the air heating systems, described in the dependencies (Eq. 3). The range of mean monthly temperature of ambient air was adopted according to SNIP 2.04.05-91 for Ural of the region.

To create the most resource-efficient heat exchangers in the article the low temperature and middle temperature of the heating system of the buildings with the following parameters the heat-carrier from +45° to +95°. With these parameters the heat exchanger of the most metal-consuming.

To identify the most critical conditions of heat exchange on the surface of the ribs considered by the turbulent mode of movement of the heat-carrier temperature of ambient air from -35° up to 10°. The analysis of use of brands fans in systems of air heating of buildings. Set the maximum speed of the air entering the heat exchanger 7 kg/(m^2·degree) which would consider in selecting the data of heat exchangers. Solution of the task is carried out with the help of the method of conjugate gradients-iterative method for unconstrained optimization of the multidimensional space of the solution of a quadratic optimization problem for a finite number of steps.

To check the adequacy of the mathematical model and definition of the experimental dependences of the temperature distribution we have developed and installed an experimental stand (Fig. 3).

This stand is certified by the federal state institution the perm centre of standardization and metrology (certificate No. 001 from 15.04.2009). Experimental stand consists of aerodynamic installations and oil circuit diagram. The design of the stand provides change of speed of movement heat transfer environments, the ability to measure the initial and final parameters (temperature, pressure and flow rate) and the stabilization of the above-mentioned parameters. Stabilization of parameters is provided by the office of the capacity of the sources of thermal energy of the stand (caldrons) as well

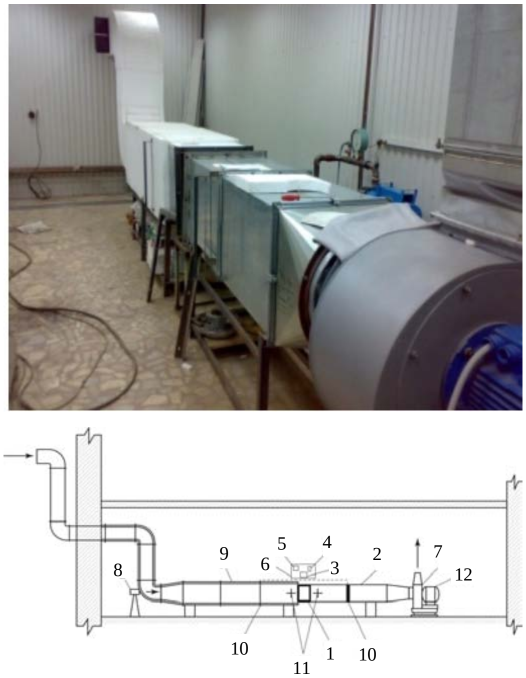

Fig. 3: The basic scheme and the general view of the wind tunnel parts of the stand for investigation of heat-releasing surface of the unit; 1: The experimental model of the element of heat-exchange apparatus; 2: Air line; 3: Registrar “Terem-4”; 4: Controller-controller “Miniterm 400-21”; 5: Heat-counter “Logic SPT 943.1”; 6: Enclosure; 7: Fan eti 14-46-5; 8: Fixing duct; 9: Insulation; 10: Grid with temperature sensors; 11: Receivers pressure; 12: Motor

as the heat insulation of the water and the aerodynamic contour. The equipment of the stand makes it possible to obtain data to determine the performance of the heat. The alignment of fields of velocities and temperatures is provided by the size of the aerodynamic parts of the stand.

To measure the costs and temperatures were used flatware, general data and characteristics of which are given below. All measuring devices registered in the State register of means of measurements. The design of the test bench provides the movement of the working environment (air, water) the possibility of measuring the start and end parameters temperature pressure and flow working environments and stabilization of these parameters when tested under the following limits:

- The temperature of air from -35° up to +35° (accuracy of maintenance of the received parameter 0.5°C)
- The temperature of the water in the circuit-from 10 up to 100°C (With the accuracy of maintenance 0.5°C)
- The speed of the air-from 0-10 m/sec accuracy of maintaining adopted by the parameter of a 0.1 m/sec)
- The speed of water -0.5 m/sec (the accuracy of the maintenance of the received parameter ±0.01 m/sec)

Air flow is measured with the help of the anemometer “Testo 450”; water-electromagnetic counterheat “the Logic of STF-943”. Air temperature thermocouples using as a secondary device of measurement of <<Terem-4>>, the water temperature is measured by a resistance thermometer with the conclusion of the heat-counter “the Logic of STF-943”. The temperature field on the surface of the fin is measured by the thermal imager “Irtis-2000”. This metrological equipment at the time of the research believe and passes periodic calibration.

A distinctive feature of this stand is the presence of a thermal imaging camera which allows the FIC is to fix the temperature field on the heat transfer surfaces of heat exchangers (Melekhin and Melekhin, 2014) (Fig. 4).

For research is designed and manufactured an experimental model of transferring element with a steel fins. The air temperature at the inlet of the heat exchanger changes due to natural-climatic factors of the region. Air speed is adjusted by means of a frequency converter installed on the motor fan.

The speed of water is regulated with the help of frequency converters of electric motors of pumps the temperature of the water-using the set point temperature with the conclusion of the electric heater boiler. For the experiment we developed a research ribs. Studied the temperature field of the ribs on 230×230 axis with an interval of 1 mm. The studies were carried out at temperatures of ambient air from -35° from 10°. In the course of the experiment was received more than 500 photos with temperatures of ambient air within a year.

Figure 5 shows one of the thermal imaging photos of the investigated surface fins. Data of temperature fields thermal imaging photos processed. On the basis of thermal imaging photos constructed the dependence of temperature distribution on the surface of the ribs at various ambient air temperatures during the heating season. The arrow shows the direction of movement of the air when carrying out the experiment.

As a software complex for solving multi-parameter nonlinear multiobjective optimization of engineering systems of buildings used IOSO NM (Egorov *et al.*, 2006).

A feature of this complex is compatible with Microsoft excel and other programs. Empirically obtained data are compiled in Excel. In the program, IOSO are

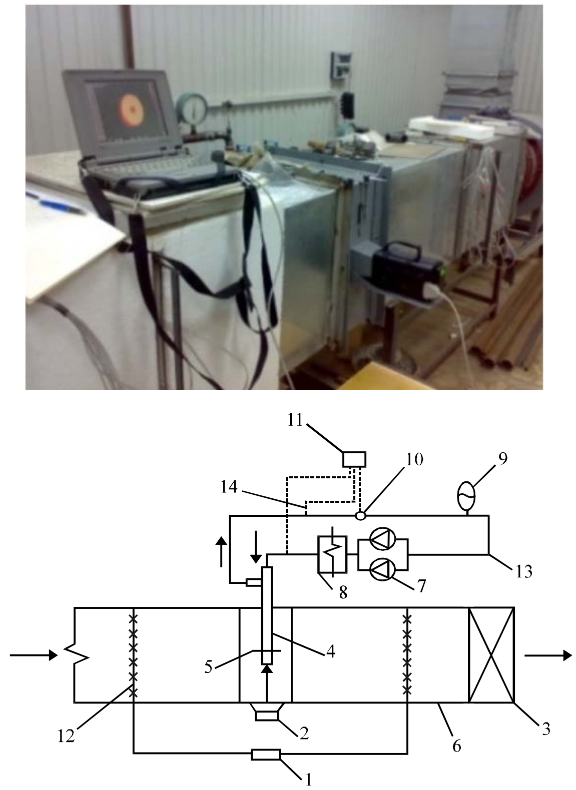

Fig. 4: The basic scheme and the general appearance of the stand for the visualization of the temperature field on the surface of the ribs; 1: The registrar of temperatures; 2: Thermal imager; 3: Ventilator; 4: The experimental model of the element of heat-exchange apparatus; 5: Plate; 6: Air line; 7: Pump; 8: Electric boiler; 9: Expansion tank; 10: Meter; 11: The heat counter; 12: Thermocouple; 13: Pipeline; 14: Converter heat

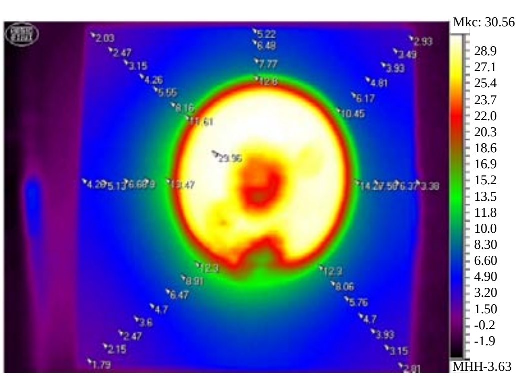

Fig. 5: Thermal imaging photos

controllable and uncontrollable parameters, optimality criteria, restrictions on the parameters of the process. Next, the program IOSO generates optimal process parameters selection method from Excel (Egorov *et al*., 2006).

Preliminary procedure IOSO is the formation of the initial experiment plan that could be implemented as a passive way (using information about various parameters, the optimization criteria and constraints obtained earlier) and active way when too much is generated in the initial search area in accordance with a given distribution law. For each vector of variable parameters the values of the optimization criteria and constraints are determined by direct appeal to the mathematical model of the investigated object. The number of points constituting the initial plan of the experiment depends on the dimension of the problem and the selected approximation functions. The mathematical model is designed for the following parameters of the process:

- The temperature at the bottom of the ribs from 45°-95°
- The temperature of air from -35° up to 10°
- Radius of the pipe without fins adopted 0.03 m const
- Radius of the pipe with finning from 0.035-0.12 m
- The thermal conductivity of the ribs from 25-40 W/(m·degree)
- The thickness of the edges adopted 0.002 m const
- Coefficients for the calculation made on the basis of modified Bessel functions

It shows Paratoo-optimal array (Kashevarova and Permyakova, 2007; Kashevarova and Martirosyan, 2013) of values of x D for solving multi-parameter optimization of a fin heat exchanger with the help of analytical software complex IOSO NM Version 3.0 b. Obtained optimal values. For easy understanding of the obtained values of the graphs obtained for each controlled parameter.

In order to analyze the obtained results for optimization models we consided the dependency of Reynolds number and the height of the ribs. Also, we explored the relation between heat transfer coefficient and Nusselt number (Nu) as well as the weight of the rib. Finally we obtained the dependency of Nusselt and Reynolds Number (Re). The described results allow to conclude about the adequacy and reliability of the suggested optimization models.

CONCLUSION

As a result of solving multivariable multiobjective optimization problem obtained optimal parameters of the fin heat exchanger for air heating systems of the building. Improving the energy efficiency of engineering systems of buildings and structures, reduction of energy consumption through the optimization of their operation, introduction of energy saving technologies and optimization of structural elements of engineering systems is important (Vilkas and Maiminas, 1981).

As applied problems of improvement of engineering systems of buildings considered an example of optimization of heat exchanger element air heating system of the building.

Finding the best managed of the parameters of the heat exchanger element air heating system of a building is possible with the developed by the researcher of a comprehensive method of research based on multi-criteria parameter optimization with the introduction of empirically obtained data. When developing a mathematical model of the heat exchanger element air heating system of a building used for the basic equations of heat and mass transfer. The decision of tasks of optimization carried out using the method of nonlinear optimization in design-software complexes IOZO.

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