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INVESTIGATIONS IN THE FIELD OF HEAT EXCHANGE AND HYDRODYNAMICS IN LITHUANIA

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Consideration is given to the general features of fundamental thermophysical and hydrodynamic investigations carried out at scientific centers of the Lithuanian Republic. They are concentrated on the study of mixed convection and thermogravitation, processes of transfer as applied to the safety of nuclear reactors, processes of combustion in boilers, thermohydraulic processes in films and cooling basins, heat and mass exchange in two-phase systems of statically stable foams, processes of evaporation of dispersed bodies in complex systems, and issues of civil-engineering thermophysics.

Thermophysical investigations in Lithuania were begun in the 1950s at the Kaunas Polytechnic Institute under the leadership and with direct participation of Algirdas Žukauskas and were later continued at the Lithuanian Academy of Sciences. The investigations mainly concerned the problems of heat exchange and hydrodynamics in different flows of viscous fluids in the case of external flow about different bodies and their systems — bundles of tubes — and also in channels and tubes with different boundary conditions. At a later stage, investigations were carried out in high-temperature gases and in a flux of low-temperature plasma (to 5000 K). The processes of erosion of heat-resistant oxide materials and ceramics were studied. In the last decade, after the joint thermophysical investigations and contractual agreements (contracts) with scientists from the republics of the former Soviet Union were discontinued, the research work was oriented toward the needs of the Lithuanian Republic, specifically toward ensuring the safety of nuclear power engineering.

At present in Lithuania, thermohydrodynamic problems are mainly investigated at the Lithuanian Power Institute, at the Kaunas University of Technology, at the Gediminas Vilnius Technical University, at the Lithuanian Institute of Architecture and Civil Engineering, and at the Institute of Heat Insulation.

We will consider below the main results of investigations at these scientific centers.

The Lithuanian Power Institute. The Lithuanian Power Institute (LPI) is the largest scientific-research center of the country, at which the main thermophysical investigations are carried out. In 1998, the government of the Lithuanian Republic approved for LPI five main programs or directions in scientific work that were closely linked to power engineering and in which a significant place was occupied by heat exchange and hydrodynamics (Fig. 1).

The *first program* dealt with investigation of the physical processes occurring at the Ignalina Nuclear Power Plant: the thermohydraulic and neutron characteristics of the reactors, the aging of the structures, the change in the properties of materials, and the consequences of potential accidents were modeled. Of particular importance was the series of investigations associated with the development of a program to improve the safety of the Ignalina Nuclear Power Plant and to prepare for obtaining a license for its operation. Work associated with the containerization of radioactive waste and spent nuclear fuel and their storage and also with the preparation for the future closure of the nuclear power plant was begun.

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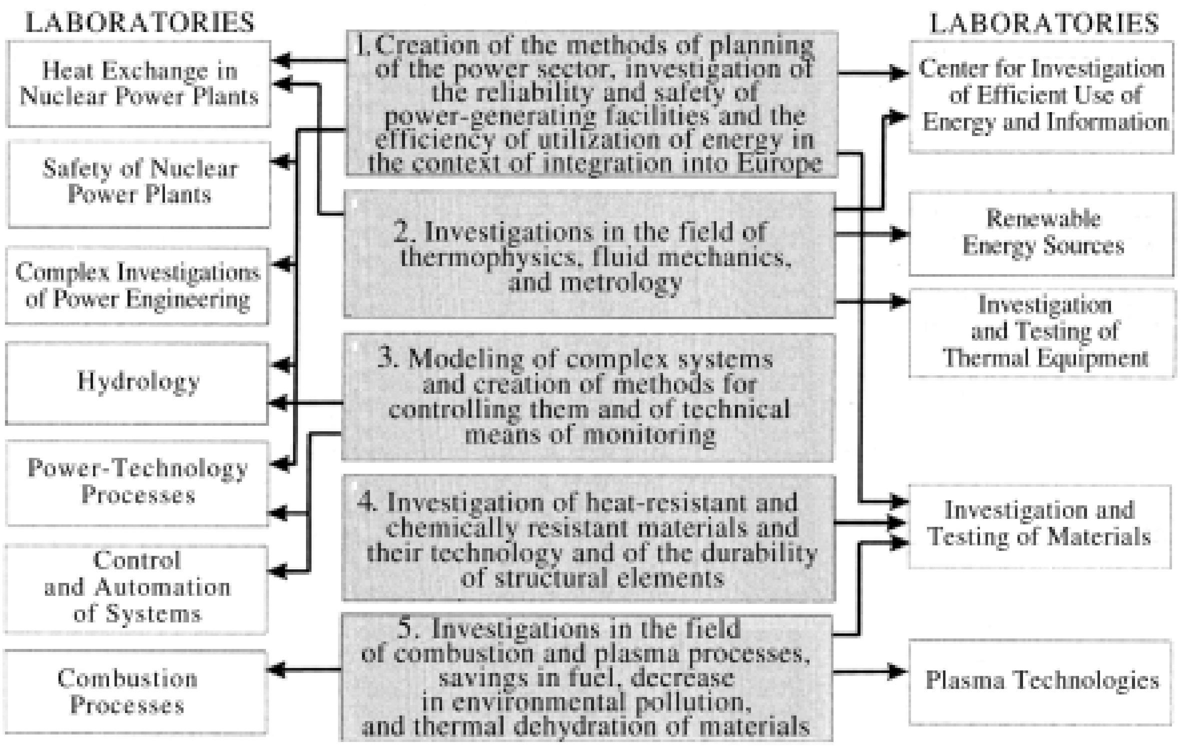
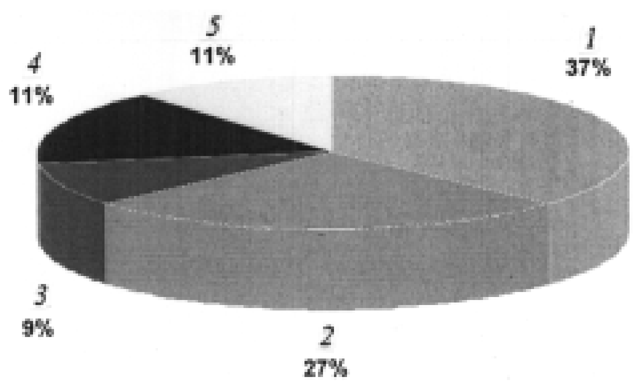


Fig. 1. Main directions in scientific investigations at the Lithuanian Power Institute.



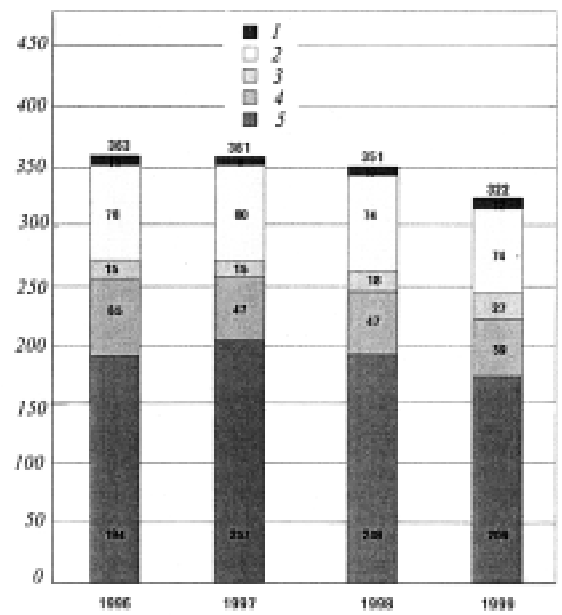


Fig. 2. Distribution of scientists in five scientific-research programs of the Institute (see Fig. 1).

Fig. 3. Dynamics of change in the composition of the Institute's staff in the period of 1996–1999: 1) doctors of sciences; 2) candidates of sciences; 3) predoctoral graduate students; 4) lecturers and reseachers; 5) engineers and technicians.

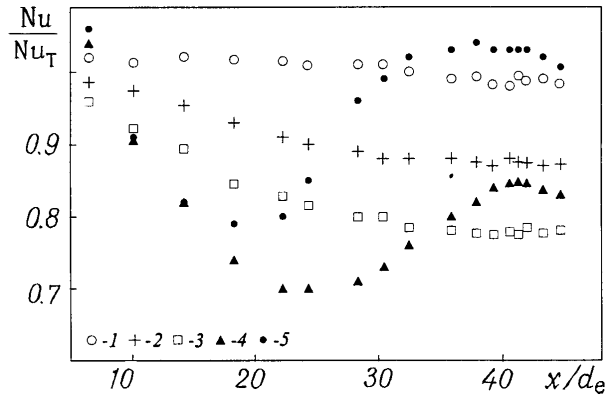


Fig. 4. Change in the relative local heat transfer along the channel length in unilateral heating. The inlet parameters are as follows: 1) $Bo_{in} = 5.6 \cdot 10^{-7}$; 2) $2.8 \cdot 10^{-6}$; 3) $4.3 \cdot 10^{-6}$; 4) $(Bo_2)_{in} = 0.05$; 5) 0.13. $Bo = Gr_q/(Re^{3.425}Pr^{0.8})$; $Bo_2 = Gr_q/(Re^{2.5}Pr)$.

The *second program* continued the old traditions of scientific investigations of hydrodynamics and heat exchange, conducting which the scientists of the Institute had accumulated a lot of experience. They carried out original investigations of the regularities of mixed convective heat transfer of surfaces of different configuration and orientation in space, a study of the processes of combustion with the aim of reducing the atmospheric pollution, and fundamental research in the field of metrology in creation of national standards to measure flows of various liquids and gases.

Within the framework of the *third program* thermophysical investigations were not carried out in practice.

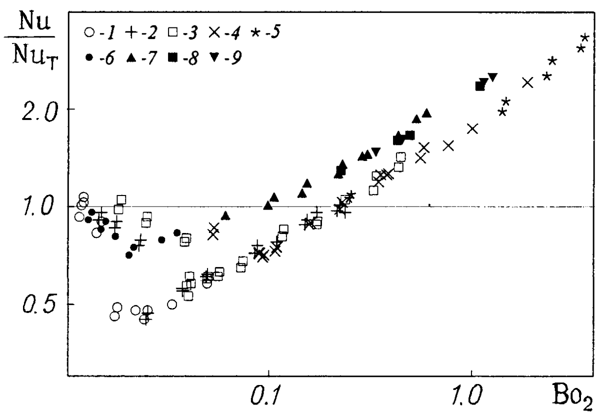
Under the *fourth program*, investigations into fire–resistant and chemically resistant materials, oriented toward the evaluation of the state of structural elements of power-generating plants and the prediction of their residual service life and also toward the creation of special polymeric composite and ceramic materials using local raw material and industrial waste, were carried out.

The most important work under the *fifth program* was the investigation of reacting turbulent flows with the aim of developing recommendations on the reduction of environmental pollution with nitrogen and carbon oxides and solid emissions; the study of the dynamics of high-temperature flows, the heat exchange in channels of different shape and size, the heat-exchanger elements in models, and also problems of thermal decontamination of liquid and solid toxic materials.

Figures 2 and 3 present some characteristics of the Institute's activities. At present, the Institute's employees annually publish about 600 papers and reports on different directions in scientific research in national and foreign publications, and also on the average 3–4 books and monographs. About 50% of the funding for the Institute's research is provided from the state budget and the same amount from different contracts.

The Laboratory of Heat Exchange in Nuclear Power Plants. At the Laboratory, investigations in the field of the influence of mass forces on turbulent transfer in channels are being continued. The problem includes the influence of thermogravitational and centrifugal forces [1–3].

Most of the investigations of heat transfer in mixed turbulent convection were carried out in vertical tubes. Different researchers showed that in the case of opposite directions of forced and natural convections heat transfer in mixed convection is higher than in purely forced one. In the case of coincident directions of forced and natural convections, laminarization of the flow and reduction in heat transfer were revealed. In case of a great influence of thermogravitational forces, turbulent transfer and heat transfer become more intense than under conditions of purely forced convection.



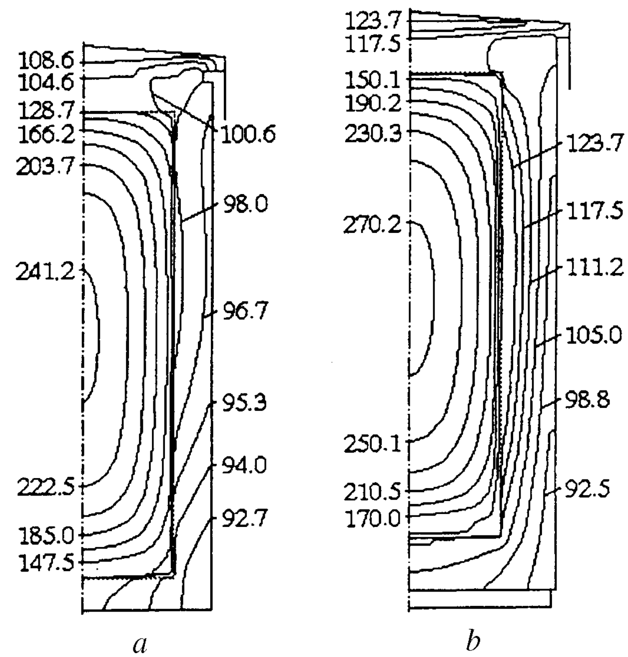


Fig. 5. Change in the relative heat transfer as a function of the parameter Bo_2 for x/d_e = 42: 1–5) bilateral heating [1) p = 0.1 MPa; 2) 0.2; 3) 0.4; 4) 0.7; 5) 1.0]; 6–9) unilateral heating [6) p = 0.1 MPa; 7) 0.4; 8) 0.7; 9) 1.0]. $Bo_2 = Gr_q/(Re^{2.5}Pr)$.

Fig. 6. Distribution of isotherms in the casings of CASTOR (a) and CONSTOR (b) containers and inside them in an extreme case in the storage facility under the conditions of just loaded spent nuclear fuel in solar radiation in summer.

Significantly fewer investigations were carried out in vertical flat channels, with the obtained results often being contradictory. Local heat transfer in a vertical flat channel with symmetric heating in the case of coincident directions of forced and natural convections was studied in detail.

The dynamics of change in the relative local heat transfer over the length of a flat channel in unilateral heating is shown in Fig. 4. It is seen that the character of the change in the heat transfer strongly depends on the value of the thermogravitation parameter. As in the case of bilateral heating, one can distinguish two groups of characteristic regimes in unilateral heating: one with a monotonic decrease in the relative heat transfer (Fig. 4, points (regimes) 2, 3) and one with its characteristic minima and maxima (Fig. 4, points 4, 5). The figure also shows a regime, pertaining to purely forced convection (points 1), as a relation of Nusselt numbers obtained in the present experiments and calculated from the dependence for purely forced convection.

In the regimes of monotonic decrease in the relative heat transfer over the tube length, the intensity of turbulent transfer gradually decreases with distance from the beginning of heating, i.e., we observe laminarization of the flow, and, as a result of this, a reduction in the relative heat transfer. The laminarization of the flow is the greater the greater the ratio x/d_e and the thermogravitation parameters. As has been noted above, such regimes include 2 and 3 (Fig. 4).

As the thermogravitation parameter increases, the position of the heat-transfer minimum clearly shifts toward the beginning of heating: from $x/d_e \approx 25$ for regime 4 to $x/d_e \approx 20$ for regime 5.

Figure 5 provides comparison of data on the relative heat transfer for $x/d_e \approx 42$ in a channel with unilateral heating with data for a channel with bilateral heating. As is seen, the reduction in the heat transfer in the case of unilateral heating due to laminarization of the flow is significantly smaller than in the case of bilateral heating.

The introduction of new technology of storage of spent nuclear fuel (SNF) at the Ignalina NPP required a detailed study of the processes of heat transfer from containers with SNF. No less than after 5 years of storage in the reactor's basins, 51 assemblies cut in the middle into two equal parts, i.e., 102 assembly halves with SNF with a total residual heat release of about 7 kW, are placed into CASTOR RBMK-1500 and CONSTOR RBMK-1500 containers of the GNB Company (Germany). The height of the containers is ~4 m, the diameter is ~2 m, and the wall thickness is ~0.3 m. In the analysis, use was made of the ALGOR (USA) computer program, making it possible in a two-dimensional formulation of the problem to find the temperature distribution over the depth of the container and the temperature of the jacket of the most heated fuel element (Fig. 6).

The Laboratory of Safety of Nuclear Power Plants. At present in Lithuania, the Ignalina Nuclear Power Plant operates two power-generating units with RBMK-1500 reactors, i.e., high-power channel reactors, the safety of which is a highly important task. In this problem, the question of heat exchange and hydrodynamics in the power-generating equipment of the RBMK-1500 is assigned a key role, since the occurrence of emergency situations at the nuclear power plant and their possible consequences are determined to a great extent by the regularities of thermohydraulic processes occurring in the power-generating equipment of the plant and first of all in the reactor's cooling system. The most important problem in raising the safety of the Ignalina Nuclear Power Plant through the introduction of safety-related modifications is reliable prediction of the change in the main parameters in the equipment elements for the entire range of postulated design accidents and reliable substantiation of the measures to ensure safe operation of the plant as the equipment ages and the gap between the technological channels and the graphite lining is exhausted and in other nonstandard situations.

The only possible means of analysis of thermohydraulic processes in the natural power-engineering equipment of a nuclear power plant is computational analysis. At the Lithuanian Power Institute, research work is carried out in the following directions related to the subjects of the Minsk forum:

(a) analysis of design transient and emergency situations in the coolant loop of the reactor;

(b) analysis of nonstandard situations: transient processes without the operation of the safety shutdown system of the reactor; transient processes due to the exhaustion of the gap between the technological channels and the graphite lining; the influence of hydraulic impacts resulting from pipeline breaks and the formed reverse flow of the coolant that leads to an abrupt shutting of the inverted valve and the pipelines adjacent to this valve;

(c) analysis of thermohydraulic processes in the system of localization of accidents.

To carry out the indicated work, the Laboratory acquired powerful workstations of the types HP Apollo 9000, IBM RISC 6000, and also IBM SP2 with four parallel processors, making it possible to do calculations using modern thermohydraulic codes such as RELAP5, ATHLET, CONTAIN, and others. Based on the indicated computer codes, the scientists of the Institute developed corresponding models required for the analysis of thermohydraulic processes occurring in different elements of the equipment and in the systems of the Ignalina Nuclear Power Plant.

The investigations carried out made it possible not only to evaluate the level of safety but also to identify the "weak" spots of the plant, and also to provide recommendations on raising the level of safety at the Ignalina Nuclear Power Plant. Below we give some results of the analysis.

Throughout the entire range of the normal regime of operation, the researchers investigated transient processes in the cases of failure of the design emergency system (control and safety system) of the reactor and determined the regimes in which safety limits can be violated. It was shown that the consequences of certain transient processes during failures of the control and safety system are unacceptable and can lead to numerous breaks of technological (fuel) channels. Specifically, in the case of de-energizing its own needs and

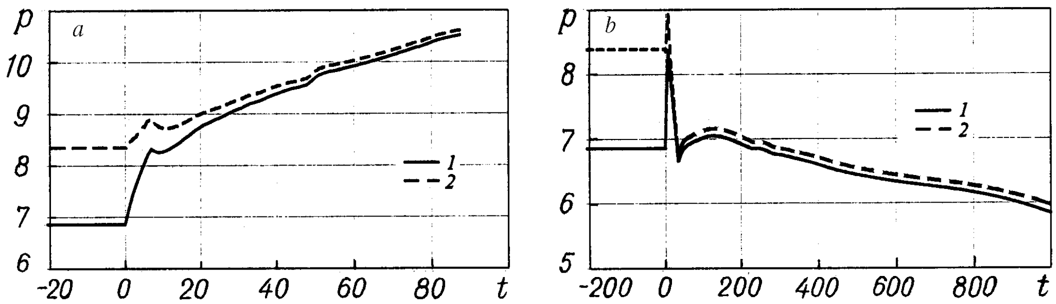


Fig. 7. Pressure change in the loop of multiple forced circulation without operation of the control and safety system (a) and with operation of the additional safety system (b): 1) drum of the separator; 2) pressurized collector. *p*, MPa, *t*, sec.

a failure of the control and safety system the pressure in the reactor coolant loop will exceed the permissible one in approximately 1 min (Fig. 7a). Therefore, an analytical base was developed and limits were determined for the operation of an additional safety system, the introduction of which makes it possible to efficiently cope with the consequences of the transient processes during failures of the existing emergency safety system of the reactor, i.e., after the introduction of the additional safety system the safety criteria for the indicated transient processes will not be violated (Fig. 7b). In 1998, an additional safety system was introduced at the first power-generating unit, and in 2000 it was introduced at the second power-generating unit of the Ignalina Nuclear Power Plant.

The investigation of the influence of hydraulic impact on the inverted valve of the distributing group collector and the adjacent pipelines demonstrate that the occurring pressure pulsations do not exceed the pressures of hydraulic tests even in the case of the most unfavorable conditions; therefore, it is improbable that the consequences of hydraulic impact can lead to a break of the coolant loop of the reactor.

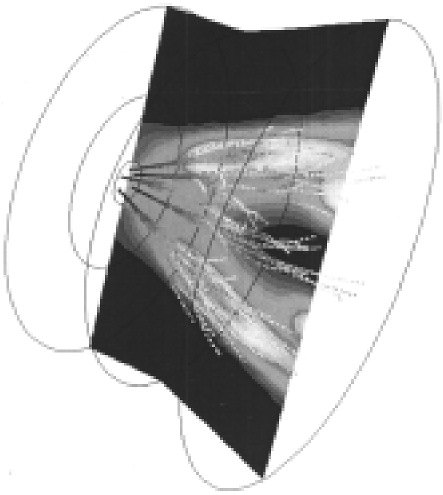
It is shown that in the case of normal operation where the gap between the technological (fuel) channel and the graphite lining decreases, the temperature of the exterior surface of the technological-channel wall increases by approximately 20–25^{o}C, whereas the temperature of the exterior surface of the graphite unit decreases by approximately 50^{o}C. The temperature gradients between the interior and exterior surfaces of the technological-channel tube and the graphite units increase approximately 2.6 times. Under normal operation and in the case of limiting transient processes, the safety criteria are not violated when the gap between the technological channel and the graphite lining is absent.

The results of work on an analysis of thermohydraulic and transient and emergency processes that occur at the Ignalina Nuclear Power Plant are generalized in [4] and have been published in a number of papers and reports [5–8].

The Laboratory of Combustion Processes. The main research direction concerns the improvement of the efficiency of combustion of organic fuel and decrease in toxic emissions into the atmosphere. Primary attention is focused on investigations of the processes of formation of nitrogen oxides and on development of methods for reducing their amount and improving the quality of burning of fuel oil in the furnaces of industrial and power-generating boilers.

Methods of control of separation of vortices and of the scale of turbulence in the boundary layer of the exit cone were developed. Factors restricting the formation of nitrogen oxides in step-by-step burning of fuel were determined. Several modifications of oil-gas burners with a low NO_x yield were designed and introduced into practice based on the obtained results.

Experimental and theoretical investigations of pulsation combustion and of the influence of the parameters of pulsations on the formation of NO_x were carried out. This combustion is distinguished by its high intensity of heat transfer and can be used in low-power hot-water boilers.



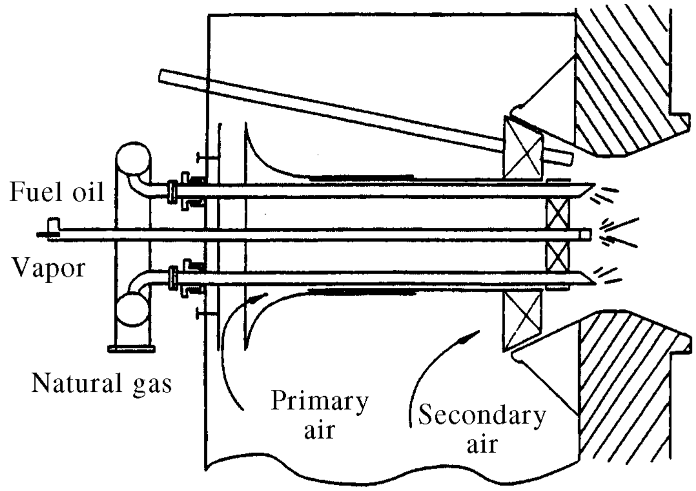


Fig. 8. Numerical modeling of the structure of the flame of fuel-oil combustion using the FLUENT software package.

Fig. 9. Scheme of a 7-MW automated oil-gas burner.

The mechanism of heterogeneous combustion of hydrocarbons in the boundary layer above the surface was studied. The aim of the investigations was to create a modern burner with preliminary gasification of fuel oil in small furnaces.

At the Laboratory, much attention is paid to the numerical methods of calculation of complex processes of heat and mass exchange in reacting media; the FLUENT software package that incorporates modern methods of calculation of three-dimensional nonstationary equations of hydrodynamics, heat transfer, and chemical reactions in multiphase media was mastered (Fig. 8).

New original computer methods of modeling the burning of solid substances are being developed, too. In cooperation with the Research Center in Carlsruhe, the TOSCA software package was developed for modeling the dynamics of solid granulated particles as applied to thermal decomposition of substances in furnaces. The procedure is based on direct calculation of the trajectories of each particle. The TOSCA package can also be used to model the dynamics of particles and molecules in chemical reactions.

The accumulated knowledge and expertise have been widely used in practice to develop and introduce burners with a low NO_x yield and efficient fuel atomizers, to design furnace devices, and to evaluate technological capabilities of enterprises for reducing toxic emissions into the atmosphere.

The main underlying agreements and work contracts imply a maximum technical and economic effect with minimum financial expenditures. To achieve this in redesigning boilers it is proposed:

(a) to replace fuel atomizers by more efficient ones that have a shorter pay-back period. In one year, the laboratory manufactures and introduces over 200 atomizers with a fuel-combustion rate of 100 to 5000 kg/h;

(b) to equalize the distribution of the air in the burner and to replace the vortex generators of the embrasure. In one year, several dozens of such re-designings are carried out;

(c) to introduce modern low-NO_x burners. At the Laboratory, standards have been obtained for the manufacture of oil-gas burners (Fig. 9) with a power of 7, 10, and 30 MW; 15 such burners have been introduced.

To dry ammonium phosphate, gas furnaces that do not need expensive lining material have been designed at the Joint-Stock Company "LIFOSA". In Lithuania, this is the first case of using the air above the flame, which is worthy of more attention since fuel oil is burned up poorly in such old-design furnaces.

Technological processes of fuel combustion have been considered and the maximum permissible emission rates have been prepared for the Joint-Stock Companies "Mažeikų nafta," "Mažeikų elektrine," "Kedainių cukrus," and other major enterprises.

At the enterprises, many problems arise which are associated with the combustion of fuel oil in steam and hot-water boilers. Therefore, advice services are offered. Every year a seminar is organized at the Laboratory of Combustion Processes for specialists working in the direction "Economical Combustion of Fuel." At the seminar, projects implemented by the Laboratory are presented and an exchange of scientific ideas and practical experience is carried out.

The Laboratory of Investigation and Testing of Materials. The Laboratory carries out investigations in the field of testing heat-proof and chemically resistant materials, technologies of their production, and durability of structural elements.

Fundamental investigations in this field are aimed at developing and testing technologies of production of ceramics and polymeric and composite materials on the basis of local raw materials and industrial waste and also at determining the reliability and predicting the durability of metal structures subject to corrosion and erosion processes.

Optimum compositions of ceramics designed for electrical and heat insulation and also structural ceramics for molding equipment were obtained. At present, a cycle of investigations of porous ceramics for the production of radiation burners has been completed and a procedure for its creation and determination of its characteristics has been developed.

The Laboratory of Investigation and Testing of Thermal Equipment. Here work has been carried out in the following directions:

(a) meteorological support for power-generating facilities of Lithuania in the field of measuring parameters of liquid and gas flows; creation and preservation of national standards, and also the maintenance of the interconnection of measurements with national and international prototype standards;

(b) testing of thermal and gas devices with a view toward assuring guarantees of their compliance with the requirements of certificates and normative documents of Lithuania and other countries of Europe and also bringing these requirements into agreement with each other;

(c) scientific research to create and improve the procedure of measuring liquid and gas flows, to establish the influence of the factors affecting the accuracy of measurement, and to determine a possible disbalance between the supply and consumption of energy resources.

Primary attention is paid to the creation and investigation of national standards. There is a marked tendency toward reproducing the appraisals of the units of velocity of air (gas) and those of volume/flow of air (gas) or liquid, and also toward using financial and material means as efficiently as possible, for which purpose use is made of direct and indirect research methods and production and scientific potential.

The results obtained are of great practical significance, specifically in the appraisal, from the meteorological viewpoint, of the amount of supplied and consumed gas in the gas facilities in Lithuania, and also in the analysis of the gas balance with the aim of its optimization.

The Laboratory of Plasma Technologies. At the Laboratory, the dynamics and heat exchange of high-temperature flows in channels of various shape and size and in models of the elements of heat exchangers are studied. The operating conditions and operating characteristics of linear electric-arc gas heaters and reactors have been studied and conditions to extend the service life of plasma generators have been determined. The characteristics of a high-temperature flow have been studied; the regularities of the distribution of velocities and temperatures and of their pulsations have been established.

Investigations of the melting of dispersed materials and ceramic materials have been conducted; the search for catalytic materials having new properties of forming of coatings has been carried out.

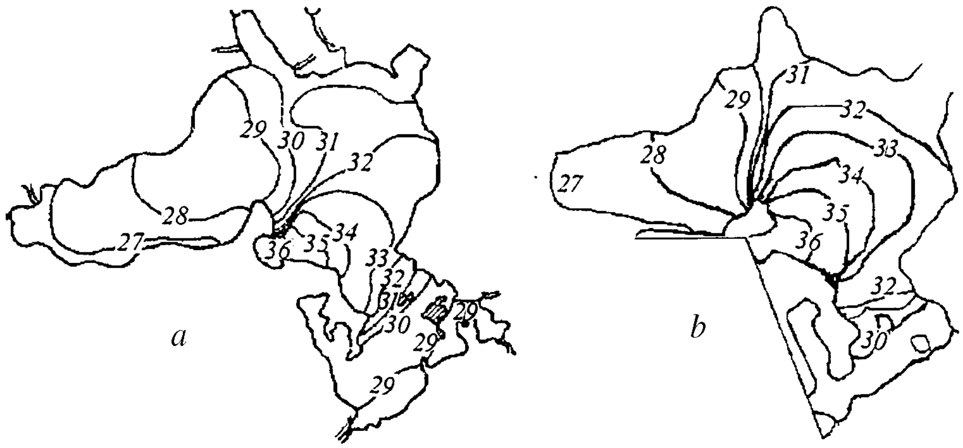


Fig. 10. Distribution of measured (a) and calculated (b) isotherms of the surface of water in Drukšiai Lake – the coolant of the Ignalina Nuclear Power Plant. The figures show the temperature, ^{o}C.

A reactor for burning harmful materials has been created and tested; it meets environment-protection requirements and conditions (the materials being decontaminated are held for over two seconds at a temperature of higher than 1200^{o}C) [9].

Possibilities are being studied for decontamination of radioactive waste by means of its fusion.

A plasma generator operating with water steam and designed to process and decontaminate waste has been improved; its electrical and thermal characteristics have been investigated.

Experimental elements of oxide catalysts have been manufactured, their characteristics under natural conditions when they are used in the exhaust pipes of cars have been investigated. If there is a sufficient amount of oxygen, the efficiency of the catalyst in the process of CO oxidation reaches 95%.

The Laboratory of Renewable Energy Sources. With the growth of the power of electric power stations and the corresponding increase in consumption of heated water and the use of deep lakes and reservoirs as coolers, it became necessary to develop new, more accurate than currently applied, methods of numerical modeling. In calculating a hydrothermal regime, it is necessary to take into account the action of wind and also buoyancy (Archimedean) forces and other features of the cooler reservoir. Furthermore, to solve practical problems it is important to know not only the value of the averaged temperature but also its distribution over the area and depth of the reservoir.

The problem is solved by mathematical modeling of general systems of equations of transfer processes and by correct formulation of the problem, relying on adequate initial field data.

For numerical modeling of hydrothermal processes, Drukšiai lake as the cooler of the Ignalina Nuclear Power Plant and the cooler reservoir of the Lithuanian Electric Power Station have been used as a model. Based on the PHOENICS software package, a numerical solution of the three-dimensional processes of transfer in the lake has been obtained. A procedure is being developed for taking into account the influence of solar radiation and of the atmosphere on the heat balance of the lake.

To determine the recirculation transfer process, three-dimensional Navier–Stokes equations and an energy equation for a quasi-two-phase flow were numerically solved.

The software package used for the calculations takes into account the influence of the physical properties of water and air, the density of water as a function of temperature, and other parameters (for example, the molecular and turbulent diffusion coefficients).

The distribution of the calculated (a) and measured (b) isotherms is presented in Fig. 10 under conditions of the absence of wind.

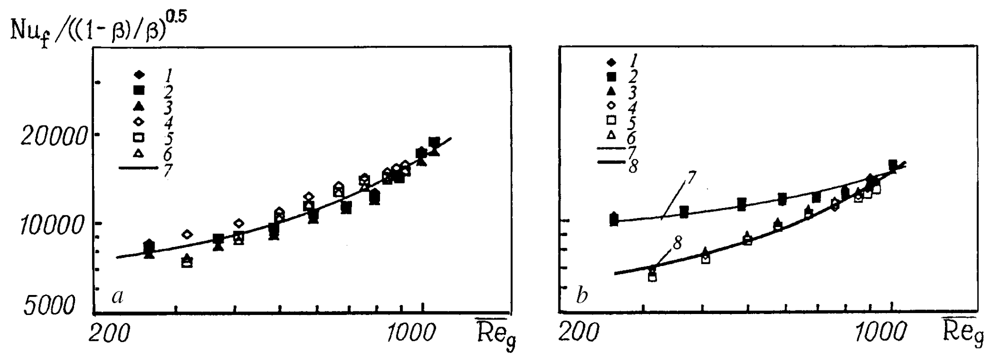


Fig. 11. Heat transfer of the first (a) and third (b) tubes in a tube bundle: 1–3) tubes in the middle row; 4–6) tubes in the last row; 1, 4) β = 0.998; 2, 5) 0.997; 3, 6) 0.996; 7, 8) $\overline{Nu}_f = c \exp(n\overline{Re})\left(\frac{1-\beta}{\beta}\right)^{0.5}$; for the middle row and the last row, respectively.

The development of a calculational procedure is being continued with account taken of the terrain and atmospheric conditions. These and other problems of heat transfer are widely discussed in [10].

Kaunas University of Technology. At the Department of Thermal and Nuclear Power, theoretical and experimental investigations of the processes of hydrodynamics and heat and mass transfer of two-phase systems — statically stable foams (SSFs) — are carried out [11].

Statically stable foams are a two-phase system (liquid-gas) consisting of polyhedral gas bubbles separated from each other by thin flat layers of a solution of detergent, i.e., of material that reduces the solution's surface-tension coefficient. The statically stable foams' part by volume reaches 99%, and the surface of interphase contact can even exceed 1000 m^2/m^3. Depending on the concentration of the detergent and the generation regime, statically stable foams are capable of existing without disintegration from several seconds to several years.

Statically stable foams are formed in various technological processes of concentration, improvement, and cleaning of solutions whose composition includes detergents. At the same time, in most cases statically stable foams are harmful; they disrupt the process and reduce its efficiency. Therefore, efforts are made to control foam formation using different mechanical, physical, and chemical methods. However, on detailed investigation of the systems of statically stable foams it turned out that in some cases foam formations did not have to be controlled or destroyed at all.

At the Department, investigations into practical application of statically stable foams are carried out in three main directions: 1) evaporation; 2) burning; 3) use for cooling surfaces.

We will mention but a few investigation results:

(a) it has been established that the intensity of heat transfer of a single cylinder is greater than that of the cylinders located in the vertical row; the intensity of the heat transfer of the first cylinder in the row is greater than that of the following cylinders;

(b) similarity equations have been obtained, using which it is possible to calculate the intensity of heat transfer of any cylinder in the vertical row to the flow of statically stable foams;

(c) the intensity of heat transfer of a staggered tube bundle to the flow of statically stable foams has been investigated; the obtained dependences have been generalized by a similarity equation, in which account is taken of the influence of the cylinder's location in the tube bundle (Fig. 11).

It is at the same Department of the Kaunas University of Technology that investigations of momentum and heat transfer in the gravitational film of a liquid started earlier by Prof. A. Gimbutis are being continued [12]. In heat engineering, in nuclear power, and also in chemical and other branches of industry, wide use is made of heat exchangers flowed about by a film of liquid that results from direct wetting of the surface by a liquid, a foam flow, or a gas-dispersed flow. Heat exchangers of this type are remarkable for their simplicity, compactness, and intense heat exchange.

In the case of a laminar high-viscosity flow of the film, the heat exchange on the initial portion of its formation on the surface in flow depends little on the conditions of its formation. In this case, the hydrodynamic stabilization of the flow of the film occurs earlier than the thermal one. Heat exchange in laminar flow of the film on its initial portion with the boundary condition q_w = const is generalized by the dependence

$$\mathrm{Nu_{df}} = 8.24\,[1 + 0.0011\,(\mathrm{Pe}\,d/x)_f^{4/3}]^{0.25}\,(\mathrm{Pr_f}/\mathrm{Pr_w})^{0.25}\,, \quad (1)$$

and in the case of stabilized flow — by the equation

$$\mathrm{Nu_{mfst}} = (0.165\,\mathrm{Re_f^{0.16}} - 0.4)\,\mathrm{Pr_f^{0.34}}\,(\mathrm{Pr_f}/\mathrm{Pr_w})^{0.25}\,. \quad (2)$$

In disperse systems, also investigated at the Department, we have an intense interphase interaction causing a change in the thermodynamic state of the system whose intensity and regularities are determined by the processes of heat and mass transfer in individual phases. In sputtering of a liquid, semitransparent droplets are formed. Investigation of the processes of heat and mass transfer in the droplet and in the environment surrounding them represents the well-known problem of a "droplet." Its solution is important in modeling the process of burning of liquid fuel, dehydration of solutions, emergency cooling of the fuel core of reactors, active suppression of a fire with a jet of sputtered water, cooling of droplets of liquid metal in open outer-space coolers, and in other heat-technology processes. Because of the combined nature of transfer, further comprehensive investigation of the closely interrelated nonstationary processes of combined heat and mass transfer in the droplets and in the carrier medium of a dispersed flow is quite topical. Investigation of the problems of heat and mass transfer in radiating disperse systems is being actively carried out by a research team made up of scientists from the Department. Investigations are being carried out in two main directions: 1) fundamental research into the regularities of the processes of nonstationary heat and mass transfer with account taken of the selectivity of radiation and of the interaction of the processes of combined transfer; 2) search for approximate methods of solving problems up to the use of principles of similarity theory.

Based on the solution of the conjugate problem of combined heat transfer for an evaporating droplet, a procedure has been created for numerical investigation of the change in a selectively radiating disperse system. Account has been taken of the dependence of the spectral optical characteristics of the droplet on temperature. A numerical solution has been found for the problem of nonstationary radiative-conductive heat transfer in a semitransparent evaporating droplet. A classification has been proposed and substantiated for the process of heating of an evaporating semitransparent droplet by the location of the maximum of the temperature field in it.

Calculations of the total heat flux of combined heat transfer (q_Σ) are significantly simplified in the case where it is determined without account taken of the interaction of (different) mechanisms of energy transfer q_Σ^0, and their relations are determined by the equations

$$\frac{q_\Sigma}{q_\Sigma^0} = 1 + B\chi\,, \quad (3)$$

where

$$B = \frac{\partial \ln q_\Sigma^0}{\partial \ln \Delta h}\,. \quad (4)$$

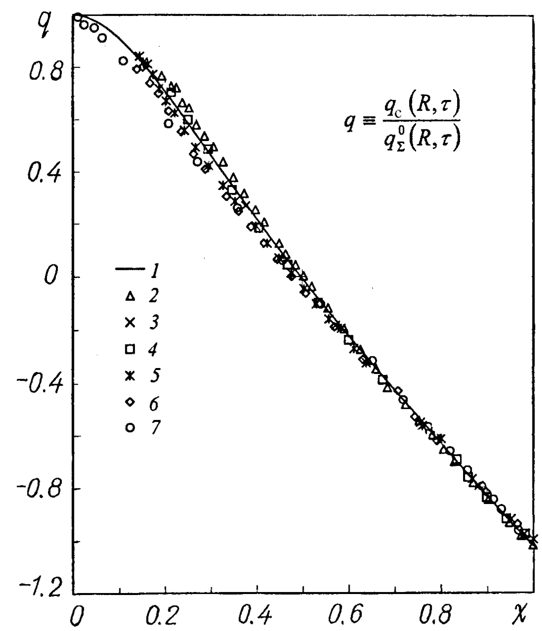


Fig. 12. Generalization of the data on the nonstationary radiative-conductive heat exchange in an evaporating droplet. The temperature of the medium T_g (K) is: 2) 1500; 3) 1273; 4) 1400; 5) 1073; 6) 873; 7) 373; 1) curve $q_1/q^0_\Sigma = 1 - 0.022\chi - 10.9\chi^2 + 22\chi^3 - 19.6\chi^4 + 6.5\chi^5$. The initial temperature of the water droplet is 300 K. $\chi = q^0_r(R)/q^0_\Sigma(R)$.

The results of a numerical investigation of combined heat transfer in evaporating droplets of water obtained at the Department show that this approach can be applied to generalize nonstationary radiant-conductive heat transfer in semitransparent droplets (Fig. 12).

The Gediminas Vilnius Technical University and the Institute of Heat Insulation. In the past few years, there has been a growing interest in problems of conserving heat in buildings serving various purposes. One of the main problems is to increase the energy efficiency of the buildings, since the supply of heat they get accounts for 40% of the entire energy consumption in the country. This subject matter is dealt with in a number of research works devoted to problems of both heat exchange of individual structural elements of the building and increasing the thermal efficiency of the heat supply. To assess heat losses through outside structures of the building, a procedure and a computer program have been developed. An analysis of the structure of heat losses through structures of an industrial building has shown that they are about 400 kW/m^2 for the entire heating period. This exceeds a similar indicator in the Scandinavian countries. The coefficient of energy efficiency helps determine correctly and plan the order of introduction of measures to reduce heat losses; it also helps establish recoupment.

To ensure warmth-keeping of the buildings it is first of all necessary to assess their heat losses correctly and then to select the most rational measures to reduce them. The most rapid and reliable way is to use computer programs for an energy analysis of buildings in use. Coefficients of convective heat transfer in the vertical walls and the ceilings in the buildings used have been determined. They have been compared to the corresponding data determined in works of other authors.

Windows in a building are the very structural elements through which an intense heat exchange occurs between the building and the environment. Owing to this, heat losses through windows can account for a significant share in the building's heat balance. Convective heat transfer on the interior surface of a window glass has a complex mechanism and depends on a number of factors. The features of the designs of the windows in the buildings in use, their technical condition, the heating and ventilation system, etc. influence convective heat transfer. Therefore, the coefficients of convective heat transfer between the building and the interior surface of the glass can be different for different types of windows.

An analysis has been made of heat consumption for heating residential buildings. Heat transfer through outside structural enclosures was experimentally investigated in three residential buildings of the city of Vilnius. Primary attention was paid to measuring the temperature fields and recording the temperature in time. Temperature changes inside and outside the buildings were recorded automatically using memory sensors, which, according to a regime programmed in advance, recorded data every hour. Stationary heat meters were used to determine heat consumption in the buildings.

Based on the presented procedure, coefficients of heat transfer through different outside enclosures and their thermal resistances, and also the density of the heat flux through them have been calculated. The heat balances of the buildings have been composed. The obtained data make it possible to suggest that the actual heat consumption is significantly lower than that cited up to now in the literature and in normative documentation. It is claimed that the heat consumption for heating buildings determined with the aid of stationary heat meters is an insufficient indicator for clarifying the expediency and efficiency of renovation of buildings.

Experimental investigations of the process of intensification of drying wood are being carried out. To this end solar and wind energy is being used. The change in the parameters and processes of heat and mass transfer in an experimental dryer has been studied. For this purpose, the process of drying was intensified by raising the temperature of the heat-transfer agent and causing forced convection.

The Lithuanian Institute of Architecture and Civil Engineering. Thermophysical investigations [13] are carried out at the Laboratory of Civil-Engineering Thermophysics of the Institute in cooperation with other research centers in two main directions: 1) climate resistance of the outside walls of buildings under conditions of a humid climate; 2) thermal regime of buildings.

In the first direction, researchers study the processes of moistening of building walls and the dynamics of thaws with subsequent periods of frost in the northwestern regions with a maritime climate, which is quite a pressing problem. They have developed scientific foundations of climate resistance of the face layer of the outside walls of buildings and prepared normative requirements on the design of these walls for various purposes under conditions of a humid climate. The particular solutions of the problem are as follows:

(a) mass transfer has been investigated on the basis of the data on the moisture regime of the walls of buildings recorded for many years at different values of microclimate parameters;

(b) a procedure for assessment of the moisture regime of the outside walls of buildings subject to oblique rains has been developed;

(c) principles of determination of the climate resistance of the outside layers of the walls of buildings have been identified; a procedure for determining modeled cycles of climate resistance for a specific building and an assigned material and for any territory has been prepared; recommendations for designing the walls of buildings, using face bricks, under conditions of a humid climate have been developed.

Specifications have been developed for other types of protective finishing coatings of walls.

In the second direction of research, heat consumption in different types of residential buildings is analyzed. Heat and mass transfer in enclosing structures of buildings and the influence of climate on the durability of the outside walls are studied. The obtained research findings are used to prepare normative documents for the design and construction of various engineering objects.

NOTATION

B, constant (4); d, diameter of the tube (channel), m; h, enthalpy, J; n, exponent; p, pressure, Pa; R, radiative component; x, length of the channel, m; q, heat flux, flux density, W/m^2; β, gas-content parameter; τ, time, sec; χ, relation of the radiative and total enthalpies; Bo, dimensionless thermogravitation parameter, Boltzmann number; Gr, Nu, Pr, Re, and Pe, Grashof, Nusselt, Prandtl, Reynolds, and Péclet numbers, respectively. Subscripts: f, m, w, and d, quantities are determined from the incoming-flow temperature, the mean temperature, the temperature on the wall, and the tube diameter, respectively; e, equivalent value; r, c, and Σ, radiative, conductive, and total components; st, stabilized flow; in, at the inlet; t, turbulent; q, from the heat flux on the surface; g, gas.

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