Institute of Continuous Media Mechanics
Ural Branch of Russian Academy of Sciences

Book of Abstracts

Russian Conference on Magnetohydrodynamics

June 18 – 21, 2018, Perm, Russia

Perm, 2018

SCIENTIFIC COMMITTEE

TOPICS

- Fundamental Problems of Magnetohydrodynamics
- Magnetohydrodynamic turbulence
- Astrophysical and Geophysical Magnetohydrodynamics
- Magnetic Fluids and Their Applications
- Soft Magnetic Matter and its Application-Oriented Aspects
- Heat and Mass Transfer in Liquid Metals (with and without magnetic field) (special section, conveners: V. Sviridov and O. Zikanov)

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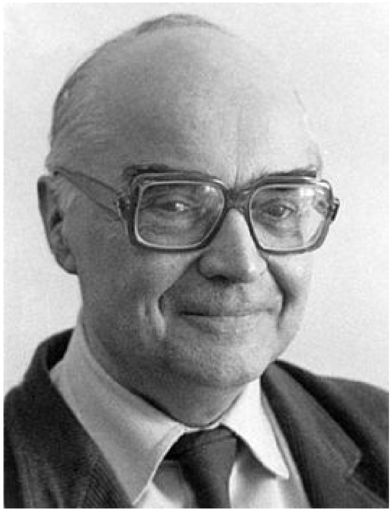
DEDICATION

The 3rd Russian Conference on Magnetohydrodynamics is dedicated to the 100-th anniversary of the birth of *Igor Mikhailovich Kirko* (16.04.1918 — 26.11.2007), who was one of the founders of magnetohydrodynamics in the Soviet Union, one of the organizers of the journal «Magnetohydrodynamics» and the creator of scientific schools of magnetohydrodynamics in Riga and Perm.



Igor Mikhailovich made an invaluable contribution to the formation and advancement of applied magnetohydrodynamics. The Magnetohydrodynamics Meetings, which were systematically conducted in Riga under his leadership and with his direct participation, brought together the leading scientists and researchers in this field and played an important role in the development of magnetohydrodynamics in the country.

The scientific works of Igor Mikhailovich are devoted to magnetism, electrohydrodynamics, the theory of ozonizers, magnetohydrodynamics of liquid metals in weak and strong magnetic fields, the problem of self-excitation of magnetic fields, the creation of energy storage system. His scientific achievements formed the basis for studying physical phenomena in magnetohydrodynamic pumps.

I. M. Kirko is the author of more than 200 works, including the monographs «The study of electromagnetic phenomena in metals by the dimensionality and similarity method» (1959), «Liquid metal in an electromagnetic field» (1964), «Magnetohydrodynamics under extreme processes» (1982), «Magnetohydrodynamics of conducting media and Plasma Physics in the Magnetohydrodynamic Approximation» (2007) and patented more than 70 inventions.

CONTENTS

THE INFLUENCE OF ROTATION MAGNETIC FIELD ON INTERPARTICLE INTERACTION PARTICLES IN MAGNETIC HYPERTHERMIA

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Magnetic hyperthermia [1,2] is a progressive method of treatment of cancer and other tumor diseases. The basic idea of this method consists in the injection of the magnetic nanoparticles into the tumor region. The particles, covered with special bioactive shells, are captures by the tumor cells. The external oscillating magnetic field, applied to the tumor region, heats the particles and hence, the cells. If the temperature of the tumor region achieves 42–50° C, the ill cells die, whereas the healthy cells, due to the higher thermal resistivity, survive. That is the key point of the therapeutic method. The main goal of the present work is the theoretically study of effect of magnetic interaction between ferromagnetic particles on the magnetic hyperthermia produced by a rotating magnetic field. We employ an interparticle interaction of magnetic nanoparticles model based on a system of nonlinear differential equations of rotation particles and stokes equations under the influence of rotation magnetic field. Computer simulation has been used to solve this system numerically and investigate of magnetic hyperthermia in the cell of tumor. The results show that the interparticle interaction under rotating magnetic field can significantly increase the heat production as compared with the calculations in the model of the interparticle interaction in linearly oscillating magnetic field.

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MIXED CONVECTION IN HORIZONTAL PIPE FLOW WITH A LONGITUDINAL MAGNETIC FIELD

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Nowadays the world community is working on the creation of an international experimental thermonuclear reactor (ITER), which is being built in Cadarache (France). Despite the water concept of cooling the reactor blanket, it is planned to design separate liquid metal modules for the production of tritium, obtained as a result of lithium irradiation by neutrons. These modules will function under a very strong magnetic fields. As a result, the research problem of the regularities of hydrodynamics and heat transfer under such conditions is actually relevant [1]. The liquid metal flow significantly depends on variety configurations of MHD parameters and may have an effect on liquid-metal heat carriers. One of the possible effect of an influence of thermo-gravitational convection (TGC), which is necessary to take into account in developing the blanket, is an appearance anomalous temperature fluctuations under spanwise magnetic field in a pipe and channel flows. This effect was approved in the experimental work [2] and numerical calculation [3]. Currently the influence of streamwise magnetic field with a joint effect of the TGC is not enough studied and lots of impacts should be investigated. The experiment work [4], for instance, shows us a nonmonotonic distribution of temperature fluctuations along the length of a horizontal pipe under conditions of uniform heating along the length and inhomogeneous heating along the perimeter of the pipe. These fluctuations are necessary to take into account in developing the ITER blanket as well. Thereby the results of the direct numerical simulation (DNS) of the MHD heat transfer in turbulent flow of liquid metal in a horizontal pipe under the joint influence of a streamwise magnetic field and TGC for a homogeneous heating are presented. All of the results are offered for the following range of the non-dimensional parameters according to experiments: the Prandtl number — Pr= 0.025; the Reynolds number — Re= 10000; the Peclet number — Pe= 272; the Hartmann number — Ha= $0 \div 600$ and the Grashof number — Gr= $0 \div 8.0 \times 10^7$. The part of results has been published in the following article [5] where numerical calculations were extrapolated with the experimental data [4]. This work remains an open question and needs a detailed development.

The results were obtained during the implementation of the Draft State Order of the Ministry of Education and Science of the Russian Federation in the field of scientific activity No. 13.9619.2017 / 8.9.

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SPACETRIPS

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spaceTRIPS is an European project involving 4 countries, French, Italy, Germany and Latvia, and 6 partners, 3 from industry (Hekyom, AREVA, Thales Alenia Space) and 3 public laboratories, the Centre National de la Recherche Scientifique (CNRS, Grenoble), The Helmholtz-Zentrum Dresden-Rossendorf (HZDR, Dresden Germany) and the Institute of physics of the University of Latvia (IPUL, Salaspils, lavia).This project is focused on the production of electricity in space by a new process based on the combination of thermoacoustic to produce mechanical energy from a heat source and on an MHD electrical generator to produce electricity. For the space application, the expected level of power is 200 W electric. In space, the heat source will be composed by nuclear elements able to deliver the thermal power during approximately 100 years. The level of power at the heat source will be about 1000 W at a temperature of about 1100 K. The cold source will be constituted by radiative cooler at a temperature of about 400 K. The thermo acoustic is a system able to produce a sonic wave on the form of pressure and velocity oscillation (vibration) which is spontaneously generated when a temperature gradient imposed on each extremity of a regenerator or a stack, is higher than a critical value that depends on several parameter and especially on the gas in which the process occurs. This vibration is transmitted to the MHD generator with the objective to transfer mechanical energy into electricity. To do that the vibration is applied at a liquid sodium located in a toroidal channel submitted to a radial DC magnetic field generated by a toroidal magnet. This produces an induced toroidal AC current that generates an AC induced magnetic field, which, by induction, produces electric current on an external coil. Therefore, there is no mechanical interaction between the external coil and the internal part of the generator as it can be seen on the figure 1.

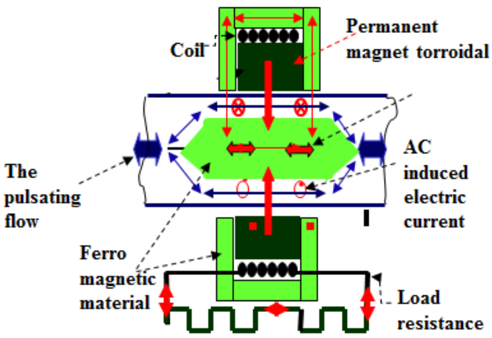

Figure 1. *Schematic representation of the MHD generator*

The coil is connected with the load. The process is interesting for space in the sense that it does not involve any moving mechanical part, it is quasi static. The Thermo acoustic/MHD generator was designed by the design office of the CNRS Grenoble, constructed and tested by the Latvian scientists of IPUL. The tests are promising. For them of course the heat source is simulated by external resistances when the cold source is simulated by cold water.

The connection between the two engines, thermoacoustic and MHD generators, is based on the Impedance adaptation that means that the relation between velocity and pressure drop must be the same for the two engines. The process is compatible with all the energy sources in particular with the solar source, the waste recoveries,etc at level of temperature between 200 up to 1000° C, and the power level can reach more than 100 kW.

ALEMANY A. «Onboard power generation to explore space», cordis@publications.europa.eu, June 2017

LOCALIZED ASYMPTOTIC SOLUTIONS OF THE LINERIZED MHD EQUATIONS

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We study system of MHD equations, linearized on a smooth pair of vector fields — main velocity field of a conducting fluid and main magnetic field. We consider initial perturbation localized near 2D surface and describe asymptotic solution of the corresponding Cauchy problem. Solution appears to be localized near three different surfaces moving along different flows. Two of these surfaces are generated by Alfven modes as well as the third one appears as a result of their interaction. We describe this interaction as well as evolution of the amplitude of perturbation.

EVOLUTION OF SMALL LOCALIZED PERTURBATIONS IN A WELL CONDUCTING FLUID

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We study evolution of small perturbations of mean velocity and magnetic fields in a well conducting fluid with high Reynolds number. We assume that Initial perturbation is localized in a small neighborhood of a 2D surface. We construct asymptotic solution of the corresponding Cauchy problem for linearized MHD system. We prove that solution is localized near three different surfaces — two of them are generated by Alfven modes and the third one — by their interaction. We describe the strength of interaction and discuss the possibility of growth of localized perturbations.

THE EFFECTS OF INTERPARTICLE DIPOLE-DIPOLE INTERACTIONS ON THE MAGNETIC SUSCEPTIBILITY SPECTRA OF SUPERPARAMAGNETIC PARTICLES

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We investigate the dynamic response of the ensemble of spherical, uniformly magnetized, uniaxis superparamagnetic nanoparticles to a weak, linear polarised AC magnetic field. It is assumed that the easy magnetization axis of all particles are codirectional and it does not change with time. The rotational motion of a particle magnetic moment is described by the probability density which is the solution of the Fokker-Planck equation. The interparticle dipolar interactions are taking into account with help of additional term into the Fokker-Plank equation; this term describes the overall magnetic field produced by all other magnetic dipoles in addition to an external AC magnetic field. The analitical expression of the probability density is evaluated and used for the calculation of the real and imaginary dynamic susceptibilities. It is shown how various features of the susceptibility spectrum of a monodisperse dispersion depend on the concentration, dipolar coupling constant, and parameter of the magnetic crystallographic anisotropy. These features are the low-frequency behaviors of the real and imaginary parts of the spectrum, and the peak position in the imaginary part.

NEGATIVE MAGNETIC EDDY DIFFUSIVITY CAUSED BY THE OSCILLATORY ALPHA-EFFECT

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We have performed an analytical and numerical study of large-scale magnetic field generation by small-scale steady space-periodic flows featuring mirror-antisymmetry. For a small scale ratio epsilon, we use asymptotic methods of the multiscale stability theory. We show that the magnetic alpha-effect produces harmonic oscillations of the mean magnetic field with order ε^{-1} time period. Magnetic field growth occurs at order ε^{-2} times due to magnetic eddy diffusivity. The increment of growth is a singular function of the direction of the magnetic mode wave vector (in contrast with parity-invariant flows, possessing no alpha-effect). Consequently, eddy diffusivity can take arbitrarily large negative values and sustain large-scale magnetic field generation for any molecular diffusivity.

SMALL-ANGLE NEUTRON SCATTERING CHARACTERIZATION OF A MAGNETORHEOLOGICAL ELASTOMER WITH CARBONYL IRON MICROSPHERES

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A magnetorheological elastomer (MRE) to be used as a dielectric material [1] for manufacturing electric capacitors [2,3] was examined by means of small-angle neutron scattering. The MRE was prepared from silicone rubber (RTV3325, Rhône-Poulenc), catalyst (60R, Rhône-Poulenc), silicone oil (Merck), and stearic acid (S4641773, Merck). As the solid filler of the composite, magnetically soft microspheres of carbonyl iron (CI) with mean diameter of about 5.0μm from Sigma was used [4]. Small-angle neutron scattering (SANS) is known to be a powerful tool for examining refined structure features of polymeric matrices and ensembles of embedded nanoparticles [5], to identify the magnetic field and nanoparticle concentration competitive effects [6], to characterize structure properties of polymer matrices of MREs with various magnetic textures [7]. In the present work, SANS method is employed for investigating the above-described MREs in order to reveal the effect of microparticles on the structure of the polymer matrix. The experimental structural data are analyzed in comparison with the results on magnetoelectric properties of the MRE samples.

Acknowledgements. The research is partially supported by 2017-2018 RO-JINR projects (Theme 04-4-1121/ 2015-2020).

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ENERGY TRANSFER IN COMPRESSIBLE MHD TURBULENCE FOR ISOTHERMAL SELF-GRAVITATING FLUIDS

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Three-dimensional, compressible, magnetohydrodynamic turbulence of an isothermal, self-gravitating fluid is analyzed using two-point statistics in the asymptotic limit of large Reynolds numbers (both kinetic and magnetic). Following an alternative formulation proposed by S. Banerjee and S. Galtier (Phys. Rev. E,93, 033120, 2016) and S. Banerjee and S. Galtier (J. Phys. A, Math. and Theor., 50, 015501, 2017), an exact relation has been derived for the total energy transfer. This approach results in a simpler relation expressed entirely in terms of mixed second-order structure functions. The kinetic, thermodynamic, magnetic and gravitational contributions to the energy transfer rate can be easily separated in the present form. By construction, the new formalism includes such additional effects as global rotation, the Hall term in the induction equation, etc. The analysis shows that solid-body rotation cannot alter the energy flux rate of compressible turbulence. However, the contribution of a uniform background magnetic field to the flux is shown to be non-trivial unlike in the incompressible case. Finally, the compressible, turbulent energy flux rate does not vanish completely due to simple alignments, which leads to a zero turbulent energy flux rate in the incompressible case.

ALFVEN WAVES AMPLIFICATION DUE TO PARAMETRIC INTERACTION WITH MAGNETOACOUSTIC WAVES IN ISENTROPICALLY UNSTABLE FULLY-IONIZED PLASMA

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One of possible mechanisms of powerful Alfven waves appearance in the lower layers of solar atmosphere is parametrical energy transfer from powerful magnetoacoustic waves to weak Alfven waves. The similar interaction was considered in [1, 2]. Two types of parametric interaction in the weak nonlinear approximation have considered in this work. The first type is the collinear quasi-resonant three wave interaction between a powerful magnetoacoustic wave and two Alfven waves in infinite conductive heat-releasing fully-ionized plasma. The second type is orthogonal parametric interaction (referred to as «swing wave-wave interaction» in [3, 4]) between an Alfven wave and a fast magnetoacoustic wave in finite conductive heat-releasing fully-ionized plasma. In the case of collinear interaction the truncated systems of equations describing non-stationary quasi-resonant interaction were obtained. The analysis of the obtained equations revealed the fact that in the case of Alfven wave decay (cs/ca1) the interaction strongly depends on the frequency detuning. When the detuning equals zero, the amplification of Alfve'n waves is resonant, non-threshold and bi-exponential. With frequency detuning increase, the parametrical amplification of Alfve'n waves becomes slower, further on, modulation is observed before bi-exponential amplification, and, finally, there is only Alfve'n wave modulation. The equation for the amplitude of the Alfven wave describing orthogonal interaction was obtained [5]. The obtained equation coincides with the Mathieu equation in the case of heat-releasing absence and infinite conductivity [3, 4]. It was shown that this interaction leads to bi-exponential growth of the Alfven wave amplitude in the isentropically unstable heat-releasing plasma. This growth is limited by the energy loss of the MA wave (disregarded in our weakly nonlinear consideration) due to the parametric energy transfer into the Alfven wave. Thus, both considered parametric interactions lead to the bi-exponential growth of the Alfven wave amplitude in the isentropically unstable heat-releasing plasma.

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INFLUENCE OF CHANNEL INCLINATION ON HEAT TRANSFER OF LIQUID METAL FLOW

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Liquid metal usage is usually connected to high thermal loads. In this case, natural convection can create considerable influence on the flow hydrodynamics. For a long time, not enough attention was given to this fact because of relatively high liquid metal heat transfer coefficients, and therefore lack of interest in studying of the detailed flow structure, for example, to enhance heat transfer. However, in last decade specific convective structures were observed experimentally in channels, that naturally evolve under the influence of strong magnetic field. Large ordered vortices can develop and stably exist in the liquid metal flow not only in conditions close to the cooling system of a tokamak, but in the absence of a strong external magnetic field (such as projects of fast nuclear reactors, liquid-metal batteries, metal oxide chemical reactors, electrolytic baths, molds) with some relations Reynolds and Grashof criteria. A clear understanding of liquid metal mixed convection laws can give innovative approaches to monitoring and diagnosing of such systems, to increase their reliability and efficiency. This work is about study of liquid metal heat transfer regularities in inclined pipes with downflow. We study experimentally influence of thermogravitation and effect of longitudinal or transverse magnetic fields. Moderate heat fluxes are chosen not to produce fluctuating regimes of flow in transverse magnetic field. Focus is on changes of temperature fields and wall temperature distribution non-uniformity.

EXPERIMENTAL INVESTIGATION OF LIQUID METAL MIXED CONVECTION AFFECTED BY TRANSVERSE MAGNETIC FIELD

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Experimental investigations of hydrodynamics and heat transfer of liquid metal flow affected by magnetic field are performed for many years by MPEI-JIHT research group. MHD-configurations close to TOKAMAK reactor conditions are studied using mercury as a model liquid. Gathered data include averaged over time temperature fields, local wall temperature distributions and statistical characteristics of temperature fluctuations in a flow. Such a detailed data has become possible due to unique micro thermocouple invasive probes technique. Deep analysis of experimental data showed that combined exposure of a strong magnetic field and buoyancy manifests itself in previously unknown forms. Among them: the existence in some modes of MHD heat transfer areas of «degraded» heat transfer, the extremely uneven distribution of heat transfer coefficients on the perimeter of a channel, abnormally high temperature fluctuations, abnormally low frequent temperature fluctuations. Area of intense fluctuations existence was explored using several experimental facilities including a new HELME Facility with magnetic fields up to 2.7 Tesla. Area where fluctuations occur and transition regions specific have been explored for round vertical tubes with down flow and uniform heating (Grashof number up to $1.2 \cdot 10^8$) as a basic configuration with clear boundary conditions.

EXPERIMENTAL INVESTIGATIONS OF MAGNETIC-HYDRODYNAMIC RESISTANCE OF FLOW OF THE LEAD-BISMUTH COOLANT IN THE TRANSVERSE MAGNETIC FIELD

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The characteristics of reducing the MHD resistance to the flow of lead-bismuth coolant were studied when the characteristics of the oxide electrically insulating coatings on the internal surfaces of the coolant flow were changed. The formation and deformation of electrically insulating coatings was carried out by controlling the oxygen content in the liquid metal coolant. The investigations were carried out with the flow of a lead-bismuth coolant in the temperature range 250-480°C, the Reynolds number range (50-350) $\times$ 10^3, the Hartmann number range 0-210 in a transverse magnetic field of intensity up to 0.7 T in the pipes of austenitic steel 08X18H10T and vanadium alloy in the state of delivery, in the same pipes with formed coatings, as well as in a tube of molybdenum glass.

EXPERIMENTAL VERIFICATION OF NUMERICAL SIMULATION OF ADAPTED MHD STIRRER

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A non-magnetic working gap is distance between lower surface of molten metal and bottom MHD stirrer, usually equal to thickness of lining. Its large size is due to protect stirrer from thermal effects of melt, but on the other hand the size of this gap is significantly reduces electromagnetic efficiency of MHD stirrer. Previously, a method for reducing a non-magnetic working gap without changing lining thickness has been proposed. It consists in use of a composite material with magnetic, dielectric and refractory properties as extensions of magnetic core teeth. Numerical simulation, which showed effectiveness of using inserts from this composite, was performed [1]. Present work is devoted to experimental verification of numerical simulation results of using magnetodielectric composite inserts to compensate a non-magnetic gap between bottom MHD stirrer and molten metal. At first stage, magnetic field induction over the MHD stirrer with and without inserts was measured. At second stage, was measured temperature of liquid metal at three points to assess efficiency of stirrer when temperature was homogenized over melt volume. Experimental data agree well with the results of numerical simulation.

1. K. Bolotin et al. «Numerical simulation of the electromagnetic stirrer adapted by using magnetodielectric composite», 2017, Magnetohydrodynamics, No. 4, 723–730.

FEATURES OF FERROCOLLOID CONVECTION IN GRAVITATIONAL AND MAGNETIC FIELDS

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Swinburne University of Technology

Results of experimental and computational studies of convection in ferrocolloids in flat layers and spherical enclosures are presented. Common flow features of instabilities leading to the onset of convection in ferrocolloids synthesised by different manufacturers using various carrier fluids (kerosene, transformer oil, polyethylsiloxane) are identified. Pure thermogravitational convection and convection arising in a magnetic field are studied. In contrast to single-phase fluids and well-mixed ferrocolloids in gravitationally stratified ferrofluids convection starts abruptly when the applied temperature gradient is gradually increased. The hysteresis is observed in a reverse transition from convection to the state of rest. This is caused by the influence of the fluid density variation caused by gravitational sedimentation and thermodiffusion of a solid phase that either enhance or suppress the density variation due to the thermal expansion of a fluid. Because of the competition of several physical effects related to compositional inhomogeneity of ferrocolloids convection arising in them near a threshold has an oscillatory character with irregular spatio-temporal evolution of flow patterns. Intermittent regimes, when convection arises and decays spontaneously, and states with convection patterns occupying only part of a flow domain are also registered. It is shown that when a uniform external magnetic field is applied to a flow system, in addition to the main destabilising effect associated with a thermal variation of the fluid magnetisation and leading to the onset of thermomagnetic convection, other factors influence the stability of mechanical equilibrium in ferrofluids and structure of the resulting flows. They include gravitational sedimentation of a solid phase and geometry and size of enclosures containing a working fluid.

MHD AND NATURAL DYNAMOS; MAGNETOCONVECTION WITH ANISOTROPIC DIFFUSION

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The Geodynamo (GD) and Solar Dynamos are important examples of the Natural Dynamo (ND). Dynamo mechanism can explain prevailing majority of Cosmic magnetic fields - various planetary fields, either at existing Dynamos (Mercury, Jupiter, Uranus…) or at extinct ones (Mars…). Diversity of the stellar magnetic fields in space scales as well as in time scales is deeper than of the planetary fields and even the extremally great magnetic fields of neutron stars can also correspond to the ND. Galactic magnetic fields are unique also in the sense that only their space distribution and time development can be observed inside the Cosmic objects as details of the ND processes. Full dynamo theory, necessary to explain almost all cosmic magnetic fields generated by ND mechanisms, is complex due to nonlinear equations. In our contribution the greater attention is focused on various linear rotating magnetoconvection models in which the influence of a priori given magnetic field on arising instabilities and their dynamics is studied. We present the newest knowledge on cosmic magnetic fields created by NDs. In mathematical approaches to NDs, numerical simulations use many different methods often related to spherical geometry. Numerical constraints in simulations often force to make computations with parameters which are problematic, because they are very far from the real values, what is typical e.g. at GD problems giving the so called GD paradox, i.e. good correspondence of GD numerical simulations results with basic features of the Geomagnetic field, despite the fact of using some parameters of nonrealistic values. The promising attempt to explain or overcome the paradox is in searching of scaling laws in which the hope is that numerical simulations reveal the behaviour in ND in asymptotic limits of problematic parameters. The numerical constraints in simpler geometries (the plane layer…) are not so serious like in the spherical geometry and the solutions related to the analogous problems are often in good correspondence in the simpler and spherical geometries. Moreover, in the simpler geometries the problems with more complex physics could be presented more transparently. The Earth's Fluid Core is driven into motion by buoyancy forces so strongly that the flow and field are turbulent, fluctuating on many length and time scales, as it is accepted by the most of geophysicists. There are forces with preferred directions (e.g. buoyancy, magnetic field, Coriolis...). Thus, the turbulence in the Core is probably anisotropic, and it is important to develop some models on anisotropy of diffusive processes in the GD. In plane layer there are examples of anisotropic diffusive processes with more complex physics. They are crucial as diffusion, variously weakening forces, can lead to a new balance of the forces with the possibility of instabilities completly different from those in the isotropic case of diffusivities. So, it is very interesting to study how the anisotropy affects the diffusion phenomena in the GD or at least in linear Rotating Magnetoconvection model in horizontal plane layer with gravity and rotation axis in vertical direction and magnetic field in horizontal direction. In this regard, we consider three simple anisotropy models: 1. Heat transport anisotropy — the thermal diffusivity coefficient is anisotropic, while the viscosity and magnetic diffusivity are isotropic, 2. Partial anisotropy — the viscosity and thermal diffusivity are anisotropic, but the magnetic diffusivity is isotropic, 3. Full anisotropy — viscosity, thermal and magnetic diffusivities are anisotropic. In these models, we analyze two distinct kinds of anisotropy: (a) Stratification Anisotropy, SA, and (b) Braginsky-Meytlis one, BM. SA preserves and BM breakes a Horizontal Isotropy. The system described by these models is prone to instabilities; the occurring of the modes of instabilities depends on parameters. It is very interesting to see that the BM anisotropy modes are very sensitive to parameters and mainly the full BM anisotropy modes. This example makes us aware about how the anisotropy of diffusive coefficients is crucial in the Geodynamo processes.

PLASMA MAGNETIC TRAP OF LINEAR MULTI-CUSP CONFIGURATION — THE COMPONENT OF A PLASMA PROPULSION ROCKET ENGINE

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The plasma device [1] constructed at the NRU «MPEI» in 2017 is a linear facility with a multi-cusp magnetic system for plasma confinement. The parameters of the facility: longitudinal magnetic field on the axis up to 10 mT, the internal diameter of the discharge chamber is 0.16 m, the length of the discharge chamber is 0.72 m. The parameters of a stationary plasma discharge in the device: discharge duration up to 10 hours or more, plasma discharge current up to 30 A, plasma density up to 10^{18} m^{-3}, electron temperature up to 4 eV with a fraction of hot electrons up to 30 eV, the flow of ions and electrons to $3 \cdot 10^{21}$ m^{-2} s^{-1}. Working gases are helium, hydrogen, argon, xenon.

Plasma turbulence, plasma propulsion in electric fields, plasma-wall interaction, testing of materials (tungsten, molybdenum, steel, etc.) with high-energy fluxes of stationary hot plasma are studied on this facility. Such investigations will make it possible to advance the understanding of plasma confinement and plasma dynamics in such system, the physics of plasma - wall interaction in a multi-cusp magnetic trap, the formation of electric fields and the plasma flux out from the trap along the magnetic field producing propulsion effects. The planned studies are aimed at assessing the prospects for using a linear magnetic trap with a relatively low longitudinal magnetic field (less than 0.01 T) and radial cusps, which ensure the stability of a plasma discharge as the component of a stationary propulsion engine with a power of up to tens of kilowatts for spacecraft required for the space interplanetary missions [2]. For the first time, it is planned comparative studies of the interaction of hot plasma with liquid metal electrodes made from lithium, tin, iron and copper, which will allow to evaluate the prospects for using such metals in plasma rocket engines.

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SIMULATION OF PERMANENT MAGNET LEVITATION IN THE MAGNETIC FLUID

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The paper concerns the numerical study of the magnetic fluid segregation and its influence on the levitation of a permanent magnet placed in a rectangular cavity with magnetic fluid. The selected geometry of the computational domain corresponds to the simplest uniaxial magneto-liquid accelerometer described in [1]. The simulation is performed with handwritten code by the Fortran programming language, and by the commercial package Comsol Multiphysics. The problem is solved in a two-dimensional formulation taking into account magnetophoresis, particle diffusion, demagnetizing fields and interparticle interactions. The convection currents are absent. Having influenced on the gravitational field and inhomogeneous magnetic field of the magnet, the initially homogeneous magnetic liquid eventually becomes spatially inhomogeneous in concentration of the magnetic phase due to the magnetophoresis and gravitational sedimentation of the particles. In the absence of convective motion, the only factor impeding this bundle is gradient diffusion. The equation obtained in [2] is used to describe the change in the volume fraction φ of colloidal particles in space and time due to gradient diffusion and magnetophoresis. Magnetization of the liquid is determined by the effective magnetic field according to the modified model [3]. The magnetic fields of the magnet and the magnetic fluid in the handwritten code are calculated with analytical formulas obtained in [4], and by the Comsol Multiphysics commercial package — with the Poisson equation. The linear dimensions of the magnet are three times smaller than the cavity size. Magnetization of the magnet is considered to be constant and independent of the properties of the liquid in which it is located. It is assumed that the magnetization vector M is directed along the x-axis. The cavity is in a gravitational field directed along the z-axis. The obtained results are compared with the results of experimental data.

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MAGNETIC FIELD GENERATION BY POINTWISE ZERO-HELICITY FLOWS

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We introduce six families of three-dimensional space-periodic steady flows of incompressible fluid, whose kinetic helicity density is zero at each point. Four families are analytically defined. Flows in four families have zero helicity spectrum. Sample flows from five families are used to study the large-scale dynamo action by the two most prominent dynamo mechanisms: the magnetic alpha-effect and negative eddy diffusivity.

The alpha-effect and eddy diffusivity tensors are calculated by rigorous asymptotic methods. Following [1,2], we consider the two-scale kinematic dynamo problem, where spatial and temporal scales of magnetic field are much larger than those of the generating fluid flow. The problem is solved by applying homogenization techniques enabling one to split the large- and small-scale dynamics. The behaviour of the large-scale magnetic field is controlled by the alpha-effect (for generic flows) or magnetic eddy diffusivity (for parity-invariant flows) tensors. These tensors emerge in calculation of the mean electromotive force and describe the influence of the interaction of the fluctuating flow velocity and magnetic field on the mean magnetic field; they are averaged vector products involving solutions to auxiliary problems for the magnetic induction operator.

Our computations demonstrate that neither zero kinetic helicity density, nor zero helicity spectrum prohibits generation of large-scale magnetic field by the magnetic alpha-effect or negative eddy diffusivity. We have also found, that the considered flows often generate small-scale field for sufficiently small magnetic molecular diffusivity. These findings indicate that the kinetic helicity and helicity spectrum are not the quantities controlling the dynamo properties of a flow regardless of whether scale separation is present or not.

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SHEAR MODULUS OF MAGNETIC ELASTOMERS WITH ANISOTROPIC STRUCTURES

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Magnetic gels and elastomers are composites of fine (usually – micron-sized) magnetic particles in polymer matrixes. Combination of physical properties of polymer and magnetic materials is very promising for many progressive technologies and attracts considerable interest of researches and engineers. If the composite is synthesized without external magnetic field, the particle distribution is rather homogeneous and isotropic. In the case when the system is polymerized under the field action, the particles, as a rule, form heterogeneous structures, which size and topology are determined by the particles concentration and the rate of the system polymerization. In part, if the concentration is low enough, the particles unite into linear chain like structures. We present results the theoretical study of effect of external magnetic field on the shear elastic modulus of magnetic gels with internal chain-like structures. The chains appear at the stage of the matrix polymerization in the presence of external magnetic field; that is why they are parallel to the field. The length of the chains is supposed much less than size of the sample. We suppose also that the composite is placed in magnetic field, perpendicular to the direction of the sample shear. We have calculated and compared with experiments [1] the magnetic shear modulus (the difference between of the shear modulus with turn on magnetic field and shear modulus without field) of structured magnetic soft material using the developed mathematical model of these systems. The agreement between experimental results and theoretical ones is good for the samples with volume concentration of the particles in the range of 10%. For higher concentrations this agreement is worse; that can be explained by appearance, besides the chains, of other structures (branched nets; bulk columns, etc). These structures and their effect on macroscopical properties of magnetic gels require special study.

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3D-STIRRING OF MELTS IN ELECTRICAL ARC FURNACES

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In the melt bath of electrical arc furnaces (EAF) the electrical current interacts with self magnetic field and generates spatial distributed electromagnetic force field, following by electro-vortex flows. Flow patterns and velocity values here depend on current supply scheme, number and relative positions of arcs and built-in bottom electrodes, as well as, on bath geometry. With this, these flows define heat-mass transfer in the melt and the technology of melting process. In the article we describe electro-vortex flows and melt stirring systems in basic EAF power supply schemes: typical 3-phases EAF; axisymmetric DC EAF UNG (direct current, universal, next generation) with one bottom electrode; DC EAF UNG with two bottom electrodes; EAF with two arcs in rectangle or cylindrical bathes, DC or AC, without bottom electrodes. All results were gotten firstly by physical modelling and can be explained by using simple models of 3d electromagnetic force fields. For today these results are realized in the system of melt stirring control for DC EAF UNG.

SATURATED DYNAMO IN A PARTLY HELICAL FLOW IN A CHANNEL

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It is well known that a helicity is one of the main factors in magnetic field self-generation. The helicity of a flow is generated by such called "divertors" inside a channel in Perm dynamo experiment. The flow of a liquid metal itself is developed when a rotating toroidal channel is suddenly broken. In a generated helical flow the dynamo action is reportedly possible. But it is supposed that a flow becomes helical and turbulent in a whole toroidal channel. In a presentation we show that an MHD dynamo is also possible at least theoretically even when a helicity is propagated only partly in a laminar flow in the channel. Magnetic Reynolds thresholds will be calculated for a range of hydrodynamical Reynolds of a flow beyond a divertor. Distributions of a velocity and a magnetic field will be shown also for a saturated regime when growing magnetic field influences on a flow backwards.

ON LONGITUDINAL SEPARATION OF A BINARY METAL MELT IN AN INCLINED THIN CAPILLARY

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The direct numerical simulation of the concentration-induced convection has been fulfilled by the method of finite differences. Binary melt of liquid eutectic metals filling inclined thin plane capillary with non-uniform temperature distribution on the boundaries is considered. It is assumed that the condition of absolute non-wetting takes place on the sidewall of the channel. As a result of this effect there is the analogue of free surface on lateral boundaries, where thermocapillary force is appeared due to the external longitudinal temperature gradient which moves liquid at a big distance along the capillary. The numerical calculations have been fulfilled in the «PGU-Kepler» supercomputer of the Research Academic Center «Parallel and Distributed Calculations» at Perm State University. Numerical code was written in programming language Fortran-90. Calculation results show that the lifting speed of returning motion in the volume is less, than on the surface, that's why heavy admixture in the stage of saturation can be accumulated nearby the lower part of the capillary. After the quick establishing the flow becomes steady and its intensity is determined as in the volume as on the surface predominantly by the Marangoni effect. The slow convective motion and processes of adsorption-desorption on the free boundary have the decisive influence upon the formation of surface and volume concentration fields and speed of components redistribution in a volume. Thus, one of the possible mechanisms of longitudinal division on components of liquid binary mixtures in thin channels has been demonstrated.

THE STUDY OF MAGNETOACTIVE ELASTOMERS USING THE FORC METHOD

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Magnetoactive elastomers are systems consisting of magnetizable particles embedded in a non-magnetic elastomeric matrix. The rheological properties of these elastomers, as it happens in ferrofluids, can be influenced by an external magnetic field. However, in magnetoactive elastomers the response also depends notably on the restoring forces and torques exerted by the matrix. These systems are becoming more and more popular and useful in applications. Thus, they can be used for the design of adaptive damping devices, stiffness tunable mounts, vibrational absorbers, force sensors and artificial muscles, soft actuators and micromanipulators.

In this work we study the properties of magnetoctive elastomers by means of computer simulations with a bead-spring model. We assume that the particles in the elastomer are magnetically hard, and we model them as soft spheres carrying a fixed permanent magnetic moment in their centres. The elastic effects of the polymer matrix on the magnetic particles are modelled by means of elastic springs with different rigidities, anchored to fixed points in space. These springs can constrain either the translations or both, the translations and the rotations of the particles. We first study the magnetic response of these systems by obtaining their conventional magnetisation loops, analysing their dependence on the rigidity of the springs and the density of the magnetic particles. We also model the irreversible deformations of the polymer matrix induced by the initial movements of the magnetic particles as a response to firstly applied magnetic fields. This is done by relaxing the stretching of the constraining springs during the first magnetisation loop. With this approach we are able to explain the difference observed experimentally for these materials in their first magnetisation loop with respect to the subsequent ones. In order to study in more detail the effect of the matrix on the internal magnetic interactions, we use the first-order reversal curve (FORC) method [1]. This method is a technique of extreme sensitivity for the analysis of experimental and theoretical hysteretic systems and is helping to understand the influence of the elastic matrix on the internal magnetic interparticle interactions and coercive forces in magnetoactive elastomers. We compare the FORC measurements obtained from our simulations with recent experimental and theoretical studies [2, 3].

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INVESTIGATION OF THE MHD-PUMP MODEL WITH INCLINED PARTITIONS IN THE CHANNEL

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This paper presents the results of tests performed with the model of a MHD pump with a channel made of stainless steel sheet. Inside the channel there are partitions that are adjacent to one of its narrow walls, disposed at a 30° angle with respect to its longitudinal axis and are not attached to its narrow walls. This design allows one to avoid stagnant zones, to fill the channel with liquid metal without air bubbles and to completely remove the metal from the channel. From the outside the channel is embraced by ferromagnetic cores located in a staggered manner. The model was tested using a gallium circuit. When an electric current was passed through the channel, electromagnetic forces causing the occurrence of a pressure difference between the outlet and inlet of the channel and a through flow in the channel arise. P-Q plots are constructed for currents 1 kA, 2 kA and 3 kA.In comparison with the previous model described in the Journal of Magnetohydrodynamics (N 3, 2017.), the model proposed here has a greater number of partitions and cores and is of less height. Due to these changes in the pump model design, at current of 3 kA, the developed pressure increases by the factor of three in a stop mode and the maximum flow rate — from 205 to 240 cm^3/s (with increasing pressure from 35 to 48 kPa, respectively. We have also performed tests with the model with only one ferromagnetic core having a magnetizing coil. At current of 3 kA, in the absence of the current in the magnetizing coil, the pressure reaches 10 kPa and the flow rate — 75 cm^3/s. Under magnetization the pressure increases to 26 kPa, and the flow rate — to 120 cm^3/s. This finding allows us to continue investigations in this direction in order to provide all the cores with magnetizing coils, which will significantly extend the applicability field of the MHD-pump with inclined partitions.

APPLICATION OF ELECTROMAGNETIC FIELDS IN MATERIAL PROCESSING, METALLURGY, CASTING AND CRYSTAL GROWTH

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Basic and applied research on Liquid Metal Technologies and Magnetohydrodynamics represents a surprising bandwidth ranging from high-temperature energy conversion, new kinds of liquid metal batteries, the production of solar-grade silicon, carbon dioxide free production of hydrogen, liquid metal targets in modern neutron sources and transmutation systems, casting of steel and light metals, welding and soldering processes, to basic laboratory experiments with relevance to liquid metal cooled systems, materials processing as well as to geo- and astrophysics.

Most of the metallurgical and crystal growth processes comprise phases with liquid metals (or liquid semiconductors with very similar properties). The application of diverse electromagnetic fields has proven to be a very effective tool of influencing and controlling such liquid metal flows and the corresponding heat and mass transport. For instance, most of the problems in casting of metal alloys affecting the product quality are associated with an improperly conditioned fluid flow during the process. Small improvements in the flow pattern can achieve therefore large effects in terms of quality assurance and energy savings.

This presentation gives an overview of the research activities at the HZDR with respect to the use of magnetic fields in metallurgy, casting and crystal growth. The experimental work is based on model experiments for the detailed investigation of flow processes under the influence of magnetic fields. This presentation presents a number of examples and discusses corresponding results in the light of the respective technologies considered.

INFLUENCE OF MODULATED AND STEADILY APPLIED TRAVELLING MAGNETIC FIELD ON LIQUID METAL STIRRING

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Contactless liquid metal stirring by traveling magnetic field (TMF) inductor is widely applied in modern metallurgy. One way to increase a stirring efficiency is to use a modulated magnetic field [1]. Investigation of the formation of electrically conductive fluid flows in pulsating and reversing traveling magnetic fields is an actual challenge. In present work we study the influence of the current and modulation parameters on the hydrodynamic characteristics of the flow. The spatial distribution of the velocity field is investigated. The goal is to reduce stagnation zones in the flow and to achieve uniform stirring.

The research is carried out by numerical simulation and experiments. The electromagnetic calculations is based on noninductive approach [2, 3]. Hydrodynamic flow was calculated by RANS turbulence model. Three-dimensional calculations are performed in the Ansys and COMSOL software. Velocity profiles are studied by the Ultrasonic Doppler Anemometer (DOP-2000, Signal processing) [2]. The investigations is carried out on gallium eutectic. The magnetic flux intensity and the total electromagnetic force dependencies on the supplying current characteristics are obtained taking into account the magnetic saturation. Three-dimensional flow RANS calculations are verified by the experimental data. The flow characteristics on the TMF inductor supplying current form dependencies are determined.

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ELECTROMAGNETIC STIRRING OF THE LIQUID CORE OF CRYSTALLIZING INGOT

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At present, in conditions of tough competition in the worldwide market, the improvement of the quality of final products, the increase in the production of high-level products, and the reduction in waste are very important.

The quality depends on a number of technical conditions, namely the casting speed, the metal temperature, the conditions of the beginning and the end of the casting, and also on the cooling conditions and is determined by the crystal structure, the conformity of the chemical composition to the requirements and the uniformity of distribution in the macrovolumes. It is suggested to use the stirring of the liquid core during crystallization to improve the quality of the ingots, which will significantly affect the quality of the structure and surface of the ingot.

In the first stage of the study, the «Ansys Multiphysics» package was used to construct a two-dimensional mathematical model for the calculation of electromagnetic and hydrodynamic processes, the distribution of the vector fields of forces and velocities in the liquid phase of the ingot was determined for three variants of coupling the inductor windings.

In the second stage of the study, in order to confirm the results of mathematical modeling, a physical model was tested. A eutectic alloy was used as the modeling metal. The measurements were carried out using the information-measuring system of the laboratory of MHD processes in metallurgy in the program "LabVIEW SignalExpress". On the physical model, electromagnetic and hydrodynamic processes were investigated.

By comparing the calculated and experimental data, the reliability of the developed mathematical model was confirmed.

The intensive mixing of the metal of the liquid core was confirmed and verified, which significantly increases the quality of the ingots without the use of alloying additives; the system for changing the pairing scheme of the coils for changing the field configuration is presented. The proposed device allows to increase the productivity of the continuous casting machine, improve the quality of ingots, reduce the percentage of defects, and reduce the unit cost of production.

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TURBULENT CONVECTIVE HEAT TRANSFER IN LIQUID METALS

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The interest in heat and mass transfer in liquid metals is largely stimulated by their application as coolants in nuclear reactors, fusion reactors and space power plants. The sodium has become the traditional coolant in existing fast neutron reactors and the use of heavy metals, lead and lead alloy with bismuth or lithium, is considered in prospective nuclear and fusion reactors. The peculiarity of liquid-metal coolants is associated, in particular, with their high thermal conductivity, which is much higher than the thermal conductivity of other types of coolants, and a relatively small kinematic viscosity (small Prandtl numbers). This means that molecular thermal conductivity makes a significant contribution to the heat transfer not only in the boundary layer, but also in the turbulent core of the flow. Therefore, the results of experimental studies of free and mixed convection of metal in pipes and long vessels oriented at different angles to the direction of gravity in the presence and absence of a magnetic field are extremely important for the design of reactor plants. The results of such studies can be used both in the design of new reactor facilities and for verification of simulation codes used in nuclear power engineering. We discuss the features of experimental studies of convective heat transfer in liquid metals and we present an overview of results of three series of experiments on turbulent convection in liquid metals. The first series includes studies of free turbulent convection of sodium in cylinders of various lengths inclined at different angles to the direction of gravity. The experiments are carried out in ICMM (Perm). The second series of work was carried out at MPEI in cooperation with JIHT (Moscow) and deals with studies of heat transfer under conditions typical for tokamak blankets, in which the joint influence of mass forces of various nature - electromagnetic force and buoyancy force - is significant. Hydrodynamics and heat transfer were studied in mercury pipe flows under strong magnetic field and different orientation with respect to gravity and the vector of magnetic field induction. The last series refers to problems of non-ferrous metallurgy and concerns the study of turbulent magnesium convection in the titanium reduction reactor.

MHD TURBULENCE IN SPIN-DOWN FLOWS OF LIQUID METALS

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Intense spin-down flows allow one to reach high magnetic Reynolds numbers in relatively small laboratory setups using moderate mass of liquid metals. The spin-down flow in toroidal channels was the first flow configuration used for studying dynamo effects in non-stationary flows. In this paper, we estimate the effect of small-scale dynamo in liquid metal spin-down flows realized in laboratory experiments [1,2,3]. Our simulations have confirmed the conclusion that the dynamo effects observed in the experiments done on gallium are weak – a slight burst of small-scale magnetic energy arises only at the highest available rotation velocity of the channel. In sodium flows, the induction effects are quite strong – an essential part of kinetic energy of sodium spin-down flows is converted into magnetic energy and dissipates because of Joule heat losses. We have extended our simulations beyond the capabilities of existing laboratory facilities and examined the spin-down flows at the channel rotation velocity $\Omega \gg 50$rps. It has been found that $\Omega \approx 100$rps is enough to reach the equipartition of magnetic and kinetic spectral power density at the lowest wave numbers (largest scales), whereas at $\Omega \gtrsim 200$rps the intensity of the magnetic field becomes comparable to the intensity of velocity field fluctuations. We have also studied the influence of the magnetic Prandtl number on the efficiency of small-scale dynamo in spin-down flows. In the experimental spin-down flows, the small-scale dynamo remains in a quasi-kinematic regime, and magnetic energy is mainly dissipated at the same scale, wherein it is converted from kinetic energy. The real small-scale dynamo starts to operate at $\mathrm{Pm} > 10^{-4}$, and the inertial range of the magnetic energy spectrum appears. Thereupon the energy dissipation is postponed to a later time and smaller scales, and the peak of turbulent energy (both kinetic and magnetic) slightly increases with Pm.

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ELECTROMAGNETIC STIRRER OF MOLTEN METAL WITH DUAL-FREQUENCY SUPPLY

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The paper presents the investigation results of an electromagnetic molten metal stirrer which supply by two voltage sources of different frequency and with a different number of phases. The stirrer is a cylindrical linear induction electric machine with a liquid metal secondary element - crucible with melt. The inductor has two parallel sections of Y-connected windings, which are powered by a three-phase power supply. The zero points of these windings are supplied by high-frequency power source. With this switching circuit, the current of both sources flows in the inductor windings, which ensures controlled mixing of the metal and its simultaneous heating. Due to this, it is possible to increase the cooling time of the molten metal in the stirrer. The electrical and energy parameters of present installation with loading are determined, taking into account the skin effect in the conductors, the power source frequency, at which the maximum axial force created in the melt is ensured. The optimal connection of the inductor windings for maximum efficiency of using a high frequency source that supplies power to the inductor through the windings zero points is shown. The electromagnetic and hydrodynamic fields in an induction stirrer with different inductor power options are investigated.

THE PRECESSION DYNAMO EXPERIMENT AT HZDR

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Cosmic magnetic fields are ubiquitous phenomena that are observed on all scales, from planets and stars to galaxies and clusters of galaxies. The origin of these fields involves the formation of electrical currents by means of complex flows of conducting fluids or plasmas. Fluid flow induced magnetic fields via this dynamo effect have also been observed in experiments, which, however, require considerable technical efforts due to the significantly smaller scales available in the laboratory. The project DRESDYN (DREsden Sodium facility for DYNamo and thermohydraulic studies) conducted at Helmholtz-Zentrum Dresden-Rossendorf (HZDR) provides a new platform for a variety of liquid sodium experiments devoted to problems of geo- and astrophysical magnetohydrodynamics. The most ambitious experiment within this project is a precession driven dynamo experiment that currently is under construction and will consist of a cylinder filled with liquid sodium that simultaneously rotates around two axes. The experiment is motivated by the idea of a precession-driven flow as a complementary energy source for the geodynamo or the ancient lunar dynamo.

In our presentation we will address corresponding numerical and experimental examinations aimed at an optimization of the precession driven flow with regard to improve the dynamo process in the planned experiment. Both approaches show that in the strongly nonlinear regime the flow is essentially composed of the directly forced primary Kelvin mode and higher modes in terms of standing inertial waves that arise from nonlinear self-interactions. A peculiarity is the resonance-like emergence of an axisymmetric mode that represents a double roll structure in the meridional plane. Kinematic simulations of the magnetic field evolution induced by the time-averaged flow yield dynamo action at critical magnetic Reynolds numbers around $\mathrm{Rm}_{crit} \sim 430$, which is well within the range of the planned liquid sodium experiment.

ON THE TURBULENCE OF FLOWS IN THE CONSTANT MAGNETIC FIELDS WITH SMALL STUART NUMBER

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In this presentation we consider the motion of the conducting liquid in constant magnetic fields with a small Stuart number. The flows, which we discuss, can have a fairly wide practical application. As follows from the experimental data, the behavior of the turbulence arising in the flow depends on the magnitude of the Stuart number. Generation of the turbulent mean helicity in such flows can occur even with zero initial helicity of the external turbulent force. The behavior of the spectra confirms this. On the other hand, helicity leads to the stability/instability of the flow.

QUASI-PERIODIC RECONNECTION IN THE EARTH'S GEOMAGNETIC TAIL: SIMULATION IN 2D RESISTIVE MHD MODEL

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The reconnection of magnetic lines of force is known to be an abrupt change of the magnetic field topology in a relatively thin antisymmetric magnetic shear. In the studies of the magnetospheric dynamics, this phenomenon is given great attention due to its determining role in the development of magnetic storms and substorms being the main factor of space «weather». Among physical mechanisms affecting the reconnection process in the magnetosphere, the resistive instabilities of the current sheets play a leading role. The most important of them is the tearing instability, which develops at the Lundquist number $Lu = \mu\sigma_p v_a l > 1$ (here σ_p and l are plasma conductivity and characteristic current layer thickness, respectively, $v_a = B(\mu\rho)^{-1/2}$ is Alfven velocity).

In this paper the influence of the the plasma conductivity on the magnetosphere response is studied numerically within the framework of the resistive two-dimensional MHD model. The 2D problem of the flow past the magnetosphere by the solar wind is solved in the meridional plane. The parameters of the solar wind with the southern direction of the interplanetary magnetic field (IMF) are set constant; it is assumed that the solution of the problem is symmetric with respect to the longitudinal axis (the axis passing through the centers of the Earth and the Sun and directed toward the Sun). The solar wind velocity and IMF induction were specified as $u_0 = -400$ km/s and $B_0 = -10^{-9}$ T. The simulation is carried out for two values of electrical conductivity σ_p — 10^{-6} S/m and 10^{-4} S/m, given by constant in the whole plasma flow region.

Calculations at $\sigma_p = 10^{-6}$ S/m (Lundquist number $Lu \sim 1$) have shown that the problem has a stationary solution in which at a distance of 35 R (R is the Earth's radius) the nightside X-point is located separating the dipole magnetic field and IMF. The energy balance is maintained by the stationary magnetospheric convection. The solution obtained is rather classical and has not pronounced features. It should only to note that the dayside reconnection is characterized by formation of a magnetic island with an O-point in the center and two X points on its northern and southern boundaries. Due to the too small dimensions, the magnetic island is not visible on the figures given in paper, but its presence is indicated by the positive derivative $\partial B_z/\partial x$ at the O-point with the coordinates (-11R, 0).

At $\sigma_p = 10^{-4}$ S/m ($Lu \sim 10$), the solution is nonstationary with the development of tearing instability in the night sector of the dipole configuration of the magnetic field. The reconnection process has a periodic character (sawtooth event) with the formation of regions of closed magnetic lines of force (plasmoids), their separation and drift downstream. This solution is given in the work of the main attention. Each cycle (period) has three distinct phases: the growth phase, the explosive phase and the recovery phase, which correlate with the temporal changes in the open MMP flux and the reconnection rate in the nightside X point. The beginning of the cycle (as well as the growth phase) is determined by the minimum of the open IMF flux and the equality of the reconnection rates in the dayside and nightside X-points. The night X-point separates the dipole magnetic field and the free IMF. In the first two phases, the magnetic energy of the magnetosphere increases due to an increase of the open IMF flux. The growth phase passes into the explosive phase at the instant of reconnection when the reconnection rate in the nightside X point becomes minimal and a new X-point is born near the body. The transition to the recovery phase begins when the reconnection velocity in the night X point and the open IMF flux are reached maximum values. During the growth phase and the explosive phase pulsations of the gasdynamic parameters are excited in the night sector of the dipole and propagate downstream. These pulsations are analyzed in their relationship with electrodynamic processes.

STUDY OF ROTATIONAL SHEAR WAVES IN VISCOELASTIC FLUIDS

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Micron-sized conducting or dielectric spherical grains immersed in a classical ideal plasma tend to attain large mean negative charge shielded by the background plasma. These mutually repellent particles of the grain-medium, interacting through a Yukawa-type potential, trapped in the sheath generated by the background plasma and external gravity, typically can attain inter-particle distances of the order of a millimeter, thus forming very low density, soft Yukawa matter. By controlling the temperature of the grain-medium using neutral atom collisions, gas-like, liquid-like and solid-like of this grain medium have been discovered wherein, the individual particle dynamics is captured and analyzed in experiments. Of particular interest is the liquid-state of this system, called a Yukawa liquid, which emerges due to strong spatial correlations, hence called strongly correlated or viscoelastic dusty plasma. Such medium can be often modelled by generalised hydrodynamics model.

In present work, we study compressibility effects on the two-dimensional strongly coupled dusty plasma by means of computational fluid dynamics (CFD) with the circular vortex flow for example, Rankine and Gaussian vortex as an initial shear flow profile. Nonlinear compressible vortex flow dynamics and nonlinear properties of such flow in the presence of variable density, pressure and electrostatic potential are addressed using a generalised compressible hydrodynamic model. To address the nonlinear properties, for example, mode-mode nonlinear interaction, wave generation due to the presence of nonlinearity in the fluid, vortex formation etc. A massively parallelized Advanced Generalized SPECTral Code (AG-Spect) has been developed and various interesting results will be presented.

STATIC MAGNETIZATION OF AN ENSEMBLE OF INTERACTING SUPERPARAMAGNETIC NANOPARTICLES

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Theoretical approach, known as the 1-st order modified mean-field model (MMF1), is used for calculating the static magnetization law of an ensemble of uniformly magnetized spherical nanoparticles, interacting within the magnetic dipole-dipole interaction. Particles are considered to be superparamagnetic ones, so the Neel rotation of the magnetic moment inside the particle is taken into account. Dipolar MMF1 corrections are obtained to the magnetization laws for the cases of textured and randomly distributed particle easy axis.

MAGNETOSTATIC ENERGY OF A FERROFLUID DROP IN EXPERIMENTAL STUDIES

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Since early 1970-s the magnetic fluids scientific community paid much attention to investigation of the problem of a single ferrofluid drop subjected to the external magnetic field. The shape of a ferrofluid drop is usually analyzed in case of the studies concerning ferrofluid emulsions, surface tension problems, applied field response problems, etc. The mentioned problems concern the analysis of the equilibrium ellipsoidal shape of the ferrofluid drop, which depends on the competition between its magnetic energy Em and its interfacial energy Es [1]. The interfacial energy is proportional to the product of the surface tension coefficient and the total surface of the drop. The magnetostatic energy Em formula is usually derived from the principle of energy conservation law: the magnetic field source is characterized by the fixed field flux [2], i.e. the media including the ferrofluid drop cannot do any work on the field source. However in laboratory experiment it is impossible to fix the field flux except for the case of the superconductive coils. The proposed work is devoted to the experimental verification of the commonly used formula for the magnetostatic energy.

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KINETIC-MHD MODELING OF THE STELLAR/SOLAR WIND INTERACTION WITH THE LOCAL INTERSTELLAR MEDIUM (LISM): EFFECTS OF STELLAR AND INTERSTELLAR MAGNETIC FIELDS

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In this talk I will review our latest progress in the modeling of the solar/stellar wind interaction with the local interstellar medium. The 3D kinetic-MHD models take into account multi-component nature of both the interstellar medium and solar/stellar winds, stellar and interstellar magnetic fields, latitudinal and time-variations of the stellar parameters, supratermal particles and interstellar dust. The effects of the azimuthal stellar magnetic field on the global astrospheric structure will be discussed and peculiarities in the distribution of the interstellar dust in astrospheres will be discussed in particular.

DYNAMO RESONANCES IN A SIMPLE DYNAMO MODEL

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Dynamo can be active in several layers of a stellar convective what opens a posibility of a resonance interaction between dynamo waves excited in different layers. Previously dynamo resonances was investigated in several papers however it remains not very clear how to separate resonance effects from a non-resonant dependence of amplitude of excited dynamo wave on the dynamo governing parameters. We suggest to use for this purpose simple finite-dimensional dynamo models and demonstrate clear resonant peaks obtained in such a model.

SELF-PROPELLED MAGNETIC FILAMENTS

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We showed recently that the static magnetic susceptibility of magnetic colloids can be altered via crosslinking them in filaments [1]. Thus, even at high temperatures, at which the correlations between non-crosslinked magnetic spherical particles are supressed by the thermal motion and, as a result, the magnetic susceptibility decreases, filaments at the same conditions remain magnetically responsive, due to the forced particle proximity [2]. In the present contribution, we combine this knowledge with the interesting experimental observation of Prof. Berret [3] from Laboratoire Matiere et Systemes Complexes, Paris: a magnetic filament in an applied AC field, depending on the frequency and viscosity of the liquid, can rotate around its centre of mass or oscillate (high frequency regime). Not only we elucidate the relationship between the length, rigidity and magnetic characteristics of the filament and its dynamic behaviour in the AC magnetic field in a fluid of given rheological properties, but also we find the optimal way of crosslinking spherical ferromagnetic colloids into a filament of a particular asymmetric shape, so that its oscillatory motion around a shifted centre of mass leads to a filament self-propulsion. Simulation approach is of great advantage here, as it provides the group of Prof. Berret with an optimal filament topology in much shorter time and “lower cost”, than the exhaustive series of experiments.

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NUMERICAL SIMULATIONS OF LIQUID MAGNESIUM TURBULENT CONVECTION USING OPENFOAM CODE WITH THE RANS APPROACH

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The work is aimed at a numerical study of the reduction process of a titanium sponge in a metallothermic reactor. Industrial titanium production is a complicated physicochemical multi-stage process based on the exothermic reaction of titanium tetrachloride with molten magnesium. Control of the process is one of the metallurgy problems, since convective flow has a primary influence on the structure of the titanium block formation.

The process takes more than two days during which the titanium sponge gradually occupies the retort. The modeling of the whole time evolution of the process requires significant amount of computational resources and impossible using DNS (Direct numerical simulation) and LES (Large eddy simulation) approach. This is one of the motivations for the numerical study using the RANS (Reynolds-Average Navier-Stokes) approach because its relatively low demands for computational resources.

The numerical code solves the Oberbeck-Boussinesq equations of thermal turbulent convection. The problem was considered for various heating configurations that occur at various stages of the actual process. The calculations were performed using a free package OpenFOAM 4.1, on the supercomputer «Triton» ICMM UrB RAS (Perm). The fields of the temperature, velocity, energy of turbulent pulsations and energy dissipation rate for various two-parameter models were analyzed. The consistency of the model is verified using results of LES simulations on grid with 3.7 million nodes [1, 2].

This study was partially supported by the Government of Perm Krai, research project No C-26/060 11.03.2016.

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NUMERICAL MODELING OF FLOWS AND SURFACE STRESSES IN MELT-OXIDE SCAB SYSTEM DURING INDUCTION HEATING

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Induction heating is widely used in metallurgy industry in processes requiring high temperatures: heat resistant alloy melting, crystal growth control, surface hardening. During the induction heating the oxide scab may be formed at the metal melt surface. This scab changes the emissivity of the surface and disturbs readouts of the pyrometer by which the melt temperature is determined. Moreover the scab getting into the mold leads to waste. Thus the making of condition, which promotes to remove scab during the melting, is actual problem. The numerical modeling is preferred technique due to significant difficulties of the physical experiments concerned with high temperatures (1500° C), strong alternating magnetic fields (10 kA/m) and closed construction of the vacuum camera containing induction furnace. The governing equation system describes free buoyancy and forced convection, generated by Lorentz force. It contains the equation of fluid motion in Boussinesq approximation taking into account electromagnetic force, the equation of heat transfer with joule heat generation and equation of continuity. At the melt surface the radiation heat exchange is described by Stefan-Boltzman law, side wall and bottom of crucible are heat-insulated, for the velocity the no-slip condition is stated for all boundaries: for bottom and wall of crucible and for the melt surface, which covered by oxide scab. The tensile strength needed for scab rupture is assumed known. The mathematical model is realized in OpenFOAM system: the new developed module lets to calculate the eddy currents magnetic field, spatial distributions of joule heat sources and Lorentz forces. The momentum and heat transfer equations of standard solver describing free thermal convection was added with Lorentz force and joule heat terms. The correctness of model was proved on the problems with known solution. The temperature and velocity fields calculated with different frequency and magnetic field strength are analyzed. The analysis of viscous stresses near the surface lets to determine places and conditions of oxide scab rupture. The results of comparison analysis of impacts different approaches (laminar and turbulent, full 3D and axisymmetric) on temperature and velocity fields are given. The problem was solved within the framework of laminar and turbulent approaches in axisymmetric and three-dimensional formulations. The RANS approach was used in describing the turbulent flow. The temperature and velocity fields were obtained and their comparative analysis was carried out within the various approaches and geometries, in which the boundaries of applicability the laminar model and axisymmetric geometry for describing the large-scale convective flow were found out. The temperature and velocity fields calculated at different frequencies were analyzed in detail. Analysis of flows and viscous intensions near the free melt surface made it possible to determine the places of rupture the oxide skin covering the surface, the strength of which was considered to be known.

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INFLUENCE OF STRONG LONGITUDINAL UNIFORM MAGNETIC FIELD ON CAPILLARY INSTABILITY OF A CYLINDRICAL JET OF MAGNETIC FLUID

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The effect of a longitudinal magnetic field on the capillary instability of a cylindrical jet of a linearly magnetizable magnetic fluid was studied theoretically in [1-3]. The classical Rayleigh theory of instability was used and it was shown, that the field has a stabilizing influence. In the experiments, for a magnetic fluid with magnetization 12 kA/m there was observed complete stabilization of the jet with a magnetic field of 130 kA/m. The jet had 150 mm length and typical diameter of 1 mm [2]. One has to note here that the model linear magnetization law is not applicable in this case. In this paper, we study the capillary instability of a jet under a strong magnetic field. We use the modified Langevin magnetization law [4], which contains two experimentally determined constants: the saturation magnetization and the initial susceptibility of the magnetic fluid. There are two dimensionless parameters in this problem: the ratio of the capillary force to the magnetic force and the ratio of the differential magnetic permeability to the magnetic permeability of the fluid. We use the tabulated data [5,6] concerning physical properties of the magnetic fluid. The characteristics of the capillary instability of a jet with diameter 1 mm are calculated in the range of the change in the magnetic field strength from zero (as in Rayleigh problem) to 120 kA/m. It is shown that the numerical value of the intensity of the applied magnetic field affects the growth rate and wavelength of the fastest growing mode significantly.

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A NUMERICAL SCHEME FOR MODELING THE FORMATION OF THE MHD PROCESS IN A GROWING EARTH

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During recent years, a large number of geodynamo models have been created, which have made significant progress in describing the current magnetic field of the Earth [1]. In addition, the influence of the growth of the Earth's body on the generation of a magnetic dipole, its variations and the possibility of generating a magnetic field before the appearance of a solid structure of the body is considered in [2, 3]. At present, the question of the formation of the magnetic field and the sources supporting it is actively studied in two directions: the expansion of the results of paleomagnetic observations and mathematical, primarily numerical, studies of possible scenarios of the evolution of the magnetic field on the basis of the dynamo theory. At the same time, the question of the time of the geomagnetic field occurrence remains controversial: whether its formation took place during the accumulation of the Earth or arose as a result of the further development of the already formed planet. This question is closely related to the problem of the stage of formation of the liquid core of the Earth. In order for the «dynamo» mechanism to work, it is necessary to have an initial source, a «seed» magnetic field. In the already formed Earth, even in the presence of a liquid core, a low-conductivity silicate mantle prevents penetration of the interplanetary field and electric currents into the core. This is evidence that the appearance of the Earth's magnetic field accompanied the growth of the liquid core at the initial stage of Earth's accumulation [4, 5]. It should be taken into account that along with the release of energy by short-living radioactive elements, the main source of heat is its release when the mass and velocity of the accumulated bodies and particles of the protoplanetary cloud fall randomly distributed over the composition, and the magnitude of all the kinetic coefficients strongly depends on temperature and pressure. The used mathematical method should provide the possibility of describing a boundary value problem for a system of nonlinear differential equations in a growing volume, taking into account phase transitions at the boundaries of inclusions that are heterogeneous in composition and temperature. For a numerical solution of this problem, we propose a control volume method using the cubed-sphere grid.

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INFLUENCE OF OHMIC AND AMBIPOLAR HEATING ON THERMAL STRUCTURE OF ACCRETION DISKS

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We investigate dynamics of the accretion disks of young stars with fossil large-scale magnetic field. Basic authors' MHD model of the accretion discs includes equations of Shakura and Sunyaev, induction equation taking into account Ohmic diffusion, magnetic ambipolar diffusion, buoyancy and the Hall effect, equations of thermal and shock ionization [1,2].

In the work, we additionally take into account in the model the influence of Ohmic and ambipolar heating on the thermal structure of the accretion disks. Structure of the accretion disks of T Tauri stars is calculated using the model. We analyze influence of considered dissipative MHD effects on the temperature of the accretion disks. Special attention is paid to the structure of the regions of low ionization fraction and effective diffusion of the magnetic field («dead» zones), where conditions are favorable for matter accumulation and planet formation.

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CONVECTION OF LIQUID SODIUM IN A VERTICAL CYLINDRICAL CHANNEL SUBJECT TO NONUNIFORM HEATING FROM ABOVE

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A closed cylindrical vessel with liquid metal, the upper part of which contains non-uniform heating/cooling systems, is considered. In the framework of this problem, the process of titanium recovery in a retort (a crucible) is modeled. It is assumed that the chemical reaction is accompanied by heat release observed predominantly in the center of the upper surface, and the lateral surface is cooled. A series of numerical and experimental studies has been performed to study the flow occurring in the channel filled with liquid sodium. The channel used in the experiment was 700 mm high and 200 mm in diameter. The external region around the heater is cooled using a plate needle heat exchanger, and the lateral sides of the vessel are thermally insulated. Measurement thermocouples are located on the upper boundary, which separates the rigid surfaces of thermal exchangers and liquid sodium. The channel also contains vertically arranged thermocouples to record the necessary information about the flow [1]. Preliminary numerical studies of this process have shown that the flow is unsteady and non-symmetric, and the most intensive flow occurs only in the upper one-third of the vessel. The values of flow velocity reach 3 cm/s. Our simulations indicate that the sensor signal makes possible the performance of a cross-correlation analysis and the evaluation of the velocity of a turbulent flow inside the vessel. During the experiments, a pronounced upward flow on the cylinder axis was discovered. This fact is confirmed in the correlation analysis of temperature fluctuations measured by central thermocouples. There is an organized upward flow of the order of magnitude of 1.5 cm/s, which is localized on the cylinder axis. Being less organized, a downflow is realized over the entire remaining part of the region or localized in a thin wall layer. The organized downflow is recorded only for the non-stationary cooling regime, when the heat exchanger operates much more efficiently compared to the heater. In the energy spectra of temperature fluctuations for the thermocouple (on the cylinder axis) closest to the heat exchanger, a short inertial interval has been identified, which is indicative of the developed turbulent convection in the vicinity of this thermocouple.

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MAGNESIUM LEVEL DETECTION IN A TITANIUM REDUCTION REACTOR

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Titanium sponge is produced by the Kroll process, which involves metallothermic reduction of titanium tetrachloride using liquid magnesium as a reductant. This process takes place in the reactor located in a furnace and filled with molten magnesium. Liquid titanium tetrachloride is poured in from the top to react with the molten magnesium at its surface, where the exothermic Kroll reduction reaction generates the titanium metal in the form of sponge which reaches the reactor bottom. An unresolved technological problem is the control of the level of magnesium during the whole process. The inductive measurement of the magnesium level in a titanium reduction reactor is a challenging task because the implementation of traditional measurement techniques is hampered by the formation of titanium sponge rings within the reactor. Recently, a novel approach to the magnesium level detection using the existing equipment of the titanium reduction reactor has been introduced when considering the unknown shape, position and electrical conductivity of the titanium sponge [1]. The method explicitly takes into account the presence of sponge rings with unknown geometry and conductivity and provides a solution of the inverse problem by a look-up-table method, based on the solution of the inductive forward problems for several tens of thousands parameter combinations.

In this work, we present the results of numerical tests, as well as the results of a laboratory experiment on modelling the above technological process. Instead of the reactor, we used a stainless steel pipe embraced by a system of coils. The reactor geometry and the location of generating and measuring coils were given in reduced scale. The liquid magnesium column of different height was modelled by aluminum cylinders. For garnisage, the rings made of the material with another electrical conductivity located on the internal surface of the pipe were employed. The frequency of current in the coils can be changed so that the magnetic field penetration depth also varies. The experiments allowed us to evaluate the measurement accuracy and the sensitivity of the proposed technique to systematic and random noise. The developed algorithm can be used for statistical data manipulation and it takes into account the prehistory of the process in order to separate deliberately false regimes.

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SURFACE WAVES IN TWO-LAYERED SYSTEM INDUCED BY THE MAGNETIC FIELD

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The work is devoted to the experimental investigation of the behavior of a ferrofluid layer lying on a liquid substrate under the influence of a vertically oscillating uniform magnetic field. Due to the presence of two interfaces (one with the air and another with liquid substrate) the ferrofluid layer is well deformed with an arbitrary low amplitudes and frequencies of magnetic field. After switching on the oscillating field the layer of the magnetic fluid undergoes periodical oscillations of the surface is due to the action of the ponderomotive periodically varying force. The increase of external magnetic field oscillation frequency promotes the regime of traveling waves turns into a regime of standing waves. This frequency decreases with the increase of the liquid thickness. The length of arising standing wave decreases with increasing of the oscillations frequency of the magnetic field strength and increases with the growth of diameter of the cell. The set of one or another mode of ferrofluid surface oscillation is determined not only by the parameters of the external magnetic field, but also by the intrinsic geometric characteristics of the two-layer system, in particular, the diameter of the cell and physico-chemical characteristics of the liquids used in the experiment. The results obtained in the study make it possible to expand the process of the evolution of multilayer systems involving ferrofluids in the magnetic field, including in the region of strong deformations. Generation of waves on the surface of a liquid as a surface management tool can be a good way to simulate various wave processes in liquids under the influence of gravitational or other accelerations under laboratory conditions.

EFFECT OF TRAVELING MAGNETIC FIELD ON MASS TRANSFER AND DOPANT SEGREGATION DURING DIRECTIONAL SOLIDIFICATION OF SEMICONDUCTORS

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The problem of studying the processes of heat and mass transfer during the growth of semiconductor single crystals is of great importance due to the rapid development of semiconductor microelectronics. The worldwide semiconductor industry is in demand for the ever-growing volumes of high-quality semiconductor single crystals with high dopant distribution uniformity, which are the basis of all modern semiconductor hardware. For optimal control of convective heat and mass transfer within the solidification process the various methods are used, such as rotation, axial and rotational vibrations, stationary and non-stationary magnetic fields. The work presents the results of numerical simulation of the traveling magnetic field (TMF) effect on mass transfer and dopant segregation during directional solidification of semiconductors [1]. The simulations were performed for two directional solidification methods: the vertical Bridgman method in form of the Vertical Gradient Freeze (VGF) setup [2] and the submerged heater method in form of the Axial Heating Process (AHP) setup [3], for similar parameter sets (materials, crystal diameter, growth rate etc.). The aim of the work is to evaluate the traveling magnetic field as a means to control the mass transfer within the melt and ultimately the dopant segregation in the grown crystal. The problems are solved in a two-dimensional non-steady axisymmetric formulation. The simulation of convective flow in the melt is carried out using the Navier-Stokes equations in the Boussinesq approximation. The traveling magnetic field is assumed to be spatially uniform; the melt boundaries are treated as electrically insulated. Both diffusion and convective mechanisms of heat and mass transfer in the melt are taken into account. The shape and position of the solidification front is unknown a priori and is subject to determination from the instant temperature distribution. The growth simulations are performed for a set of Ga:Ge and GaAs crystals with up to 10.2 cm. (4 inch) in diameter [4] for both VGF and AHP setups. The upward and downward traveling magnetic fields of 300 Hz frequency and up to 10 mT induction is employed. It is shown that the TMF poses considerable effect on the meridional flow pattern and intensity and consequently on dopant distribution within the melt. Depending on run direction the TMF either intensifies the meridional convection in the area above the solid-liquid interface or dampens it which has a strong effect on the interface curvature. The TMF is shown to substantially decrease of the radial dopant concentration non-uniformity in the AHP-grown crystal under certain temperature profiles on submerged heater by increasing the melt flow and consequently the dopant transport intensity above the solid-liquid interface near the axis of symmetry.

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EFFECT OF MHD STIRRER PLACEMENT RELATIVE TO CRUCIBLE BOTTOM ON A LIQUID METAL FLOW

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Magnetohydrodynamic (MHD) stirrers are widely used in the production of cylindrical ingots from aluminum and its alloys to improve the quality of the molten metal. An MHD stirrer is usually mounted on the upper part of the crystallizer of a continuous casting machine and creates, through an electromagnetic action, liquid metal stirring. MHD stirrers commonly used in continuous casting machines induce a rotating magnetic field that generates the strong rotation motion of liquid metal and thus its efficient stirring. Over recent years, stirrers able to create both rotating and travelling magnetic fields have appeared which ensure generation of both variable rotational (toroidal) and vertical (poloidal) flows in the molten metal. Because of the design of continuous casting machines, the zone of crystallization of metal in a crystallizer with hot- top is located beneath the lower edge of the MHD stirrer, i.e. in the region where the electromagnetic forces generated by the inductor are practically absent. Hence, it can be suggested that at an increased distance of the crystallization front from the lower edge of the inductor of the MHD-stirrer , the stirring flow above this front weakens. To overcome this difficulty and to produce a metal of required quality, it is necessary that the stirring flow in the region of metal crystallization be of sufficient intensity. The objective of this research is to study the influence of a distance between the crystallization front and the lower edge of the MHD stirrer inductor bore (δ) on the rate of stirring. In our experiment a cylindrical crucible with gallium alloy simulates a crystallizer with hot- top of a continuous casting machine. The bottom of the crucible is located at different distances from the lower edge of the inductor bore of the MHD stirrer and simulates the front of ingot crystallization. Analysis of the results of physical and numerical experiments carried out in terms of the model $k-\epsilon$ for turbulent flows has revealed that in the case of a toroidal flow of liquid metal the azimuthal velocity decreases only slightly with increasing distance from the crucible bottom to the edge of the inductor bore of the MHD stirrer. The azimuthal velocity also decreases when the additional poloidal flow is initiated via the generation of a travelling magnetic field in the crucible. The numerical experiment has indicated that the intensity of the vertical flow increases in the range of the examined distances (δ), and the total kinetic energy of the resulting flow first increases at increased δ and then decreases. So, the use of MHD stirrers in continuous casting machines requires consideration of the influence of a distance between the metal crystallization front and the lower edge of the inductor of the MHD stirrer on the intensity of MHD stirring.

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THE FLOW OF A LIQUID GALLIUM ALLOY IN A CYLINDRICAL CRUCIBLE UNDER THE ACTION OF INTERMITTENT TRAVELLING AND ROTATING MAGNETIC FIELDS

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Semicontinuous cylindrical ingots made of aluminum and aluminum-based alloys and having a homogeneous fine-grained structure are currently produced using crystallizer with hot-top, in which the molten metal is stirred during crystallization by means of a special MHD stirrer. In order to improve the quality of ingots, it has been recently proposed to be stirred the melt by the joint action of travelling and rotating fields with a possibility to regulate their intensity separately. The simultaneous action of travelling and rotating fields on the molten metal is not equal to the sum of effects of these fields taken separately. Under joint influence of these fields, additional forces arise due to the cross-interaction of one field with the induction current generated by another field. This gives rise to different asymmetries in the stirring flow driven by these forces. In order to generate a flat crystallization front in the crucible, an effort must be done to create symmetric toroidal and poloidal stationary flows of liquid metal above the crystallization front. This objective can be attained by eliminating the occurrence of forces related to the cross-interaction of travelling and rotating magnetic fields with the currents induced by them. Therefore, it is interesting to consider the situation when the travelling and rotating magnetic fields do not work continuously and simultaneously, but are activated and deactivated at certain intervals; at time when one field is activated, the other should be deactivated, and vice versa. The results of the experiments have indicated that the intermittent action of travelling and rotating magnetic fields on the metal reduces to some extent the flow intensity compared to the flow generated by the continuous action of these fields. At equal activation and deactivation intervals, the flow intensity within the examined range of these intervals does not change significantly, and the topology of the metal flow in the crucible is different from that observed under the continuous action of travelling and rotating magnetic fields. When the intervals of interruption of an electric current in inductors are varied, the flow topology remains almost the same.

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WAVE BREAKING ON THE FREE SURFACE OF A LIQUID DIELECTRIC IN TANGENTIAL ELECTRIC FIELD: WEAKLY AND STRONGLY NONLINEAR MODELS

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Nonlinear dynamics of the free surface of an ideal incompressible non-conducting fluid subjected by tangential electric field is investigated in the present work. We use two numerical models for the description of fluid flow. The first one is based on so-called conformal transform (the region occupied by liquid is transformed into a half-plane). This approach allows simulating strongly nonlinear dynamics of the free surface. The second method uses weakly nonlinear approximation, i.e. the amplitudes of surface perturbations are considered to be small. Its advantages are the ease of implementation and the possibility of simulation of the surface wave turbulence. Results of simulation for both models show that the interaction of surface waves leads to the transfer of energy in small scales (the direct energy cascade is observed). The strongly nonlinear model predicts formation of regions with steep wave front at the fluid surface; where the dynamical pressure and pressure exerted by electric field undergo a rupture. The simulation results for the weakly nonlinear model show that field pressure remains smooth, but its gradient undergoes a discontinuity. Thus, both models predict similar behavior: the regions with a high energy concentration are formed on the free surface of liquid. The revealed fact is very important, since the appearance of singularities can lead to the development of turbulence of the surface waves.

DEPENDENCE OF MAGNETIC FLUID VISCOSITY ON CONCENTRATION OF SOLID PARTICLES AND TEMPERATURE

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The present work is devoted to a study concerning the dependence of magnetic fluid viscosity on concentration of magnetic particles and temperature. Two magnetic fluids — one of them is based on kerosene and the other one is based on undecane — are used in our experiments. Solid magnetite particles, whose average size is of 9 nm, are stabilized by oleic acid. The fluid viscosity is measured by a VPJ-2 capillary viscometer. A VPJ-2 viscometer is applied to measure viscosity of transparent fluids. A magnetic fluid is opaque, so a special fluid level sensor with high sensitivity to changes in thermal conductivity of the sensor environment is designed. The sensors are made of copper-constantan thermocouples that in combination with a microvoltmeter and a clock allow measuring the time interval required for a control volume of magnetic fluid flowing through a capillary of the viscometer. The obtained results are consistent with the results of previous works. In particular, the fact that the dependence of magnetic fluid viscosity on temperature is approximated by the dependence of carrier fluid viscosity on temperature as particle volume fraction decreases has already been established in experiments on non-magnetic nanofluids [1]. The results of viscosity measurements have shown that the modified Chong model [2, 3] approximates the experimental data better than the other models do, but it gives only a qualitative description. To have a more accurate description, one should find an approximate dependence for each magnetic fluid and its temperature. As a result, a wide variety of models has been developed. It can be explained by the strong viscosity dependence on characteristics of aggregates, which occur in magnetic fluids. Like in colloidal fluids, there is an aggregate size distribution in magnetic fluids. This distribution depends on temperature. In particular, an average size of aggregates decreases with increasing temperature. It reduces one of the coefficients in the Chong model. It can be assumed that aggregates break down and the coefficient becomes close to Einstein's coefficient equal to 2.5 due to the intensive thermal motion of individual solid particles and carrier-fluid molecules [4]. A similar conclusion concerning the change in a size of aggregates with increasing temperature has been made after the analysis of convective experiment results [5] obtained for an undecane-based magnetic fluid. It lends credibility to the research findings presented in this paper.

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LIQUID SODIUM CONVECTION IN AN INCLINED CYLINDER OF UNIT ASPECT RATIO

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The effect of inclination of the low Prandtl number turbulent convection in a cylinder of unit aspect ratio was studied experimentally. The working fluid was sodium (Prandtl number $Pr = 0.0094$), the measurements were performed for the fixed Rayleigh number $Ra = (1.67 \pm 0.02) \cdot 10^7$, the inclination angle varied from $\beta = 0°$ (the Rayleigh-Benard convection, the temperature gradient is vertical) up to $\beta = 90°$ (the applied temperature gradient is horizontal) with a step $\Delta\beta = 10°$. The effective axial heat flux characterized by the Nusselt number is minimal at $\beta = 0°$ and demonstrates a smooth growth with the increase of cylinder inclination, reaching a maximum at angle $\beta \approx 70°$ and decreasing with further increase of β. The maximal value of normalized Nusselt number $Nu(\beta)/Nu(0)$ was 1.21. In general the dependence $Nu(\beta)$ in cylinder with unit aspect ratio is similar to what was observed in sodium convection in inclined long cylinders [1, 2], but is much weaker. The structure of the flow undergoes essential transformation with inclination. Under moderate inclination ($\beta \leq 30°$) the fluctuations are strong and are provided by regular oscillations of LSC (large-scale circulation) and by turbulence. Under large inclination ($\beta > 60°$) the LSC is regular and the turbulence is weak, while in transient regimes ($30° < \beta < 60°$) the LSC fluctuations are weak and the turbulence decreases with inclination. The maximum of Nusselt number corresponds to the border of transient and large inclinations. We find the first evidence of strong LCS fluctuations in low Prandtl number convective flow under moderate inclination. The rms azimuthal fluctuations of LSC being about 27° at $\beta = 0°$, decreases almost linear up to $\beta = 30°$, where it is about 9°. The angular fluctuations in the vicinity of end faces are much stronger (about 37° at $\beta = 0°$) and weakly decrease up to $\beta = 20°$. Strong anticorrelation of fluctuations in two halves of cylinder indicates torsional character of LSC fluctuations. At $\beta = 30°$, the intensity of oscillations at the periphery of the cylinder falls sharply to the level of oscillations in the central plane and the anticorrelation disappears — the torsional fluctuations vanish.

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CREATION OF HOMOGENEOUS BOUNDARY CONDITIONS FOR EXPERIMENTAL STUDIES OF SODIUM CONVECTION.

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The general problem of convective experiments with low Prandtl number liquids (liquid metals) is that the thermal conductivity of the working fluid is comparable to that of traditional copper heat exchangers (HE). This leads to nonstationarity of the boundary conditions as a result of the thermal effect of the working fluid on the HE. To resolve this problem, a special kind of HE were designed and studied. Their peculiarity is that instead of traditional thick copper plates, thin plates, intensively washed with liquid sodium, are used. The required flow of sodium in the chambers of HE is provided by travelling magnetic field (TMF), like in MHD stirrers [1,2]. To optimize the parameters of HE, three-dimensional calculations have been performed for liquid sodium using Ansys. Calculations of the electrodynamic part showed that the magnetic field and the induced electric current are localized in the inductor region and do not affect the process in the convective cell. the em-force generates a toroidal vortex. The change of the TMF direction leads to change of the em-force and vortex rotation direction. The em-force is localized in the narrow near-wall layer. The sodium mixing efficiency in HE was studied experimentally by analysing the signals of nine submerged thermocouples. The efficiency of mixing was estimated by parameter $A = \langle|\langle T\rangle_t - \langle\langle T\rangle_t\rangle_v|\rangle_v$, where T is the temperature, $\langle..\rangle_t$ is averaging over time, $\langle..\rangle_v$ is averaging over volume. Without mixing, the value of A is maximal. The enhancement of mixing leads to decrease of this parameter. This indicates the decrease in the difference between the thermocouple readings and consequently leads to the homogenization of the temperature field.

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STUDY OF VERTICAL LIQUID METAL FLOW HYDRODYNAMICS AND HEAT EXCHANGE ALONG A RECTANGULAR SECTION CHANNEL IN A COPLANAR MAGNETIC FIELD

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Liquid metals (LM) are considered as promising coolants in TOKAMAK type TNR to cool the blanket and diverter due to their good thermophysical properties: the high boiling point at atmospheric pressure and low vapor pressure, which distinguishes them from traditional coolants. LM is preferable in hybrid reactor projects with thermonuclear neutron sources (TIN) since they practically cause no hindrance to neutron velocity. The BL-modules of the blanket at the international ITER TNR under construction is designed primarily for the production of tritium. The main problem with the use of LM in TNR is the large pressure loss during flow in the TOKAMAK MF. The Indian-Russian Blanket Test Module (BTM) concept with a dual cooling system, with helium as a coolant, while lithium-lead eutectic Pb-Li (LLE) cools the tritium production zone, minimizes these losses. Ascending and descending LM flow is to occur in the vertical heat exchange channels of the rectangular section located in the coplanar MF. Heat transfer during LM flow in the TNR channels will be very different from coolant flow in conventional energy devices due to the presence of an MF and this requires experimental studies. Complex studies of the hydrodynamics and heat transfer during the flow of mercury in pipes and channels in the unique mercury MHD generator MEI-OIVT RAS (USU Mercury MHD-generator) have been conducted for many years. The latest experimental data were obtained in experiments in a vertical channel of a rectangular cross-section at a ratio of 3/1 in a coplanar MF with a descending flow of mercury. Investigations of local temperature and velocity fields were carried out by probe methods using microthermal sensors. The notion-isothermicity of the LM flow led to a significant effect of thermogravitational convection caused by buoyancy forces. MF changes the structure of the flow and suppresses turbulent transport, which reduces heat transfer. In this case, large-scale secondary vortex flows of TGC are formed in the MF, with axes parallel to the vector of magnetic induction. This effect leads to the generation of low-frequency fluctuations of anomalously high intensity. Such fluctuations are dangerous for the wall of the heat exchanger since they easily penetrate it and can cause premature fatigue failure due to the variable thermal stresses. Hydrodynamics and heat transfer were studied for vertical liquid metal (LM) flow along a rectangular section with a side ratio of 3/1 in a coplanar magnetic field (MF) when heated unilaterally. The task simulates LM flow in the heat exchange channel of the liquid metal module cooling system of a thermonuclear reactor (TNR) blanket like TOKAMAK. The experiments were carried out on a mercury-based magnetohydrodynamic (MHD) generator. This article shows the average velocity and temperature profiles, the distribution of dimensionless wall temperatures along the perimeter of the channel and the characteristics of the temperature fluctuations of the flow. We obtained the distributions of the averaged and fluctuating wall temperatures along the channel length and the criterial dependences of heat transfer characteristics. In a number of flow regimes, effects associated with an increase in the intensity of temperature fluctuations in a coplanar magnetic field were observed. The authors believe that thermogravitational convection (TGC) causes the formation and detachment of large-scale vortex structures near the heated wall, the axis of rotation of which is parallel to the induction vector of the MF. These vortex formations cause temperature fluctuations, with a number of regimes exceeding the level of turbulent fluctuations. The obtained data on heat transfer should be taken into account when designing the MHD cooling channels of the TNR. It would be interesting to know what could be observed in the case of an ascending flow in the MF, where the influence of TGC contributes to the stability of the flow.

HYDRODYNAMICS AND HEAT TRANSFER OF MOLTEN SALTS IN THE FUSION REACTOR TOKAMAK

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Until recently, liquid metals, that is, liquids with a Prandtl number Pr 1, which are molten salts, these questions have not been studied, and the available experimental information indicates that these effects can be significant even at relatively small Hartmann numbers Ha, and it is impossible to neglect this influence. Within the framework of the present work, a study was carried out of the turbulent MHD flow and heat transfer in a transverse magnetic field at the Ha and Re numbers which characteristic for a tokamak using the RANS and DNS methods. Testing of design models was carried out on model liquids, such as water and aqueous solutions of electrolytes. The results of the calculations show that the combined action of the magnetic field and thermogravitational convection on the flow and heat transfer can be significant. Although the effect of the magnetic field alone is rather weak.

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INFLUENCE OF DIPOLAR INTERACTIONS ON THE MAGNETIC SUSCEPTIBILITY SPECTRA OF THE FERROFLUIDS

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The present work is devoted to the study of the influence of dipolar interactions on the dynamic magnetic response of a ferrofluid in applied AC and DC magnetic fields. The frequency-dependent magnetic susceptibility is calculated under the assumption that the constituent particles undergo Brownian relaxation only. The direction of DC and AC fields is perpendicular to each other; AC field is weak and linearly polarized. The theory is based on the Fokker-Planck-Brown (FPB) equation and includes the effects of interparticle dipole-dipole interactions with help of the effective field potential in the first order of concentration. The solution of the FPB equation describing the orientational probability density of a randomly chosen dipolar particle is expressed as a series in terms of the spherical harmonics. The analytical formula for the probability density truncated at the fifth spherical harmonics is evaluated and used for the calculation of the magnetization and dynamic susceptibility spectra. A good agreement between the theory and the results of computer simulation suggests that obtained approximation can accurately describe the dynamic response of real ferrofluids in which interparticle interactions play an important role.

INSTABILITIES IN MIXED CONVECTION AT MODERATE AND STRONG MAGNETIC FIELDS

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Flows of liquid metals under the influence of magnetic fields are encountered in a wide variety of circumstances ranging from electromagnetic flow control in metallurgy, to heat transfer in solar thermal power plants to the generation and dynamics of the magnetic field of the Earth.

In spite of significant research that has been carried out in the past years (e.g., the Collaborative Research Center SFB 609 at TU Dresden, the Research Training Group GRK 1567 at TU Ilmenau, the LIMTECH project within Helmholtz alliance, Fusion Science and Technology Center UCLA, NIIEFA, Nizhny Novgorod State Technical University n.a. R.E. Alekseev (NNSTU), Joint group of MPEI-JIHT RAS) our understanding of liquid metal MHD flows in the presence of magnetic fields and high heat loads is still insufficiently advanced. Complexity of the problem is in fundamental questions of thermo-magnetic processes in liquid metals affected by magnetic fields, which are sufficiently strong to induce Lorentz forces that dominate both inertial and viscous forces and completely change the nature of the flow.

Here, in the conditions of complete turbulence suppression by the magnetic field, thermal convection may lead to large-scale secondary structures causing high-amplitude spatial and temporal variations of temperature. Such behavior in first approach is negative from engineering point of view, as it produces additional thermal stresses to construction material and provoke corrosion. From another point of view such an issue lead to additional flow stirring, which can be useful, for example, to align temperature field in case of non-uniform heating (external or internal). This determines interest to researches providing methods to prevent or control MHD-flow behavior in described conditions.

In our work convective instabilities and development of secondary structures are investigated using high-resolution numerical simulations and experiments. We study downflow in a duct affected by transverse magnetic field directed parallel to the duct longer side (coplanar). Experiments are being performed to create a robust map of the target flow regimes which are used to validate numerical simulations. Numerical simulations are being performed to explore various ways of influence on the flow which than will be examined experimentally.

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IMMERSED TRANSIENT EDDY CURRENT FLOW METERING: A CALIBRATION-FREE VELOCITY MEASUREMENT TECHNIQUE FOR LIQUID METALS

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Eddy current flow meters are widely used for measuring the flow velocity of electrically conducting fluids. Since the flow induced perturbations of a magnetic field depend both on the geometry and the conductivity of the fluid, extensive calibration is needed to get accurate results. Transient eddy current flow metering has been developed to overcome this problem. It relies on tracking the position of an impressed eddy current system that is moving with the same velocity as the conductive fluid. We present an immersed version of this measurement technique and demonstrate its viability by numerical simulations and a first experimental validation.

MAGNETIC FIELD INDUCED BIAXIAL ORDER IN NEMATIC LIQUID CRYSTALS DOPED WITH MAGNETIC NANOPARTICLES

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The effect of an external magnetic field on the orientational order of a nematic liquid crystal (NLC) doped with rod-like magnetic nanoparticles has been studied using Landau - de Gennes phenomenological theory. We have proposed the form of the free energy, which in the absence of an external field leads to three isomorphic solutions for the order parameters, corresponding to alignment of magnetic and liquid-crystalline subsystems along three principal axes. We consider mainly the case of soft homeotropic coupling conditions where nanoparticles tend to be oriented perpendicularly to NLC director due to elastic forces in the field absence. Application of a magnetic field removes the degeneracy of these solutions, and for NLCs having positive diamagnetic susceptibility anisotropy, the uniaxial solution with nanoparticles alignment along the field direction is energetically favorable.

We take into account the soft coupling between magnetic nanoparticles and NLC and calculate the equilibrium reorientation angles of nanoparticles and NLC when an external field applied. Simulations were carried out at various temperatures, for which we varied the concentration of impurity, coupling strength and imposed external field.

The theory is applied to the description of the switching transition in a homogeneous external magnetic field. A phase diagram is constructed, which exhibits a transition from perpendicular to parallel orientation of the director relative to the magnetic field, both as functions of temperature and a concentration. We have shown that is the initial state corresponds to magnetization parallel to the field and due to homeotropic coupling the director perpendicular to the field, then under the field action this state changes by a so-called saturation state, in which the director and magnetization are parallel to the applied field. The possibility of magnetic field induced biaxiality is discussed. We have studied the phase transitions from the uniaxial to biaxial phase under magnetic field action. The theory predicted that the biaxial phase is thermodynamically unstable in the absence of an external field, but becomes stable under the field action.

The temperature and the field dependencies of the order parameters of magnetic and liquid-crystalline subsystems have been studied.

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CONTROL OF ELECTROMAGNETICALLY INDUCED FLOW AND ITS EFFECT ON MICROSTRUCTURE FORMATION IN THE SPACE EXPERIMENT PERITEKTICA (PARSEC) ON BOARD OF THE ISS

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The PERITEKTICA (PARSEC) space experiment has been performed on board of the International Space Station (ISS) starting from 2012 jointly by ESA, Roscosmos and NASA. Its implementation plan includes comprehensive theoretical and experimental study of the effect of electromagnetic stirring on transport phenomena and solidification pathways in undercooled metallic melts. Experimental measurements are performed using the MSL-EML equipment which is a developed by ESA mobile version of the electromagnetic levitation furnace.

In undercooled Fe-Co molten droplets processed by electromagnetic levitation, either single or double step recalescence is registered under terrestrial and microgravity conditions. At deep undercoolings, primary formation of the metastable bcc phase is followed by nucleation of the stable fcc phase with competitive growth of both phases. In the present work, experimental data on $Fe_{50}Co_{50}$ are tested using thermodynamic analysis and computer simulation of the conjugated fluid flow, heat transfer and multiphase nucleation at the controlled level of convection.

It has been shown that primary nucleation is well described by classical nucleation theory of heterogeneous nucleation only if a proper evaluation of size distribution and catalytic activity of heterogeneous nucleation sites (HNS) is introduced into the model. Comparative analysis with the mechanism of transient nucleation in metallic glasses by Kelton and Greer is suggested. The effect of weak reactive wetting as the main limiting factor for primary nucleation is proposed which agrees to the experiment. Secondary nucleation occurs due to the peritectic $\delta + L \rightarrow \gamma$ reaction inside the metastable bcc phase with the delay time which is a function of an initial undercooling and frequency of coherent atom jumps. Therefore a clear correlation between the flow conditions and solidification paths is confirmed and analyzed.

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COMPUTATIONAL AND EXPERIMENTAL STUDIES ON THE MIXING PROCESS OF SODIUM COOLANT FLOWS WITH DIFFERENT TEMPERATURES DOWNSTREAM OF A BAFFLE IN A CHANNEL

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To extend the service life and to enhance safety of the sodium cooled BN-600, BN-800 reactors and of the BN-1200 reactor under design, detailed studies on thermal-hydraulic processes are required. One of such processes, which has a considerable effect upon safety of the reactors, is anisothermic coolant mixing. When flows with different temperatures are mixed, temperature pulsations occur, which produce additional thermocyclic loads upon the equipment and the pipelines. Thermal pulsations have a considerable effect upon the lifetime of structures and even lead to crack initiation [1], [2]. The anisothermic mixing process may be modeled by computer fluid dynamics methods (CFD codes). However, the application of CFD codes to the sodium coolant requires that additional verification be made vs. experimental data obtained in sodium test facilities. As experimental data, results are adopted of the studies on the mixing process of sodium flows with different temperatures downstream of a baffle in a channel. The studies are performed in the facilities of the Institute of Continuous Media Mechanics, the Ural Branch of Russian Academy of Science. The channel with the baffle is a joint of stainless steel pipes 42.5 mm in diameter with the 1.5 mm pipe wall thickness. In the pipe, a longitudinal leak-tight baffle is installed that divides the pipe in halves. In either half, honeycombs are installed to form "hot" and "cold" sodium flows. Then, the sodium flows come to the cylindrical pipe segment without a baffle (mixing segment) where the mixing process of two flows with different temperatures takes place. The studies are conducted for four test modes that differ in combinations of sodium flow rates and temperatures coming to the channel. To conduct computational studies and to make subsequent comparison with experimental data, the ANSYS CFX computer fluid dynamics code is used with the LES approach. As a result of the numerical simulation, the following is obtained: velocity and temperature fields in the structure symmetry plane for the four modes; temperature variations vs. time in reference data points used to calculate the average temperature and root-mean-square deviations of temperature pulsations. The results calculated by ANSYS CFX have shown satisfactory agreement with the experimental data, and the error of the average sodium flow temperature in reference data points is below 13%.

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EQUILIBRIUM MAGNETIZATION OF A QUASI-SPHERICAL CLUSTER OF SINGLE-DOMAIN PARTICLES

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Equilibrium magnetization curve of a rigid quasi-spherical cluster of uniaxial single-domain particles is investigated numerically using the stochastic Landau-Lifshitz-Gilbert equation. The spatial and orientation distribution of particles within the cluster is random and uniform. Dipole-dipole interactions between particles are taken into account. It is shown that the system magnetization is generally lower than predicted by the classical Langevin model and that both anisotropy and interactions contribute to the magnetization decrease. For magnetically isotropic particles, the initial slope of the magnetization curve can be successfully described by the modified mean-field model, which was originally proposed for the description of concentrated ferrofluids. In moderate and strong fields, the theory overestimates the cluster magnetization. Possible ways to improve the agreement between the theory and simulations are discussed.

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OPTIMIZATION OF OUTER CORE FOR END EFFECT REDUCTION OF ANNULAR LINEAR MHD PUMP

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An annular linear magnetohydrodynamic (MHD) pump which has optimized geometric shape to decrease the end effect is analyzed for decreasing the magnetic field distortion at both ends of the pump to improve the pump performance. The intermediate heat exchanger (IHX) of the Prototype Generation-IV Sodium-cooled Fast Reactor (PGSFR) is a counter-current flow type heat exchanger that transports heat from the primary heat transport system (PHTS) sodium coolant to the intermediate heat transport system (IHTS) sodium coolant. The IHX has a dominant impact on the performance of the heat transport system of the PGSFR. Therefore, the heat exchange on the components of the coolant system and the heat transfer in the IHX must be identified by an appropriate simulation in the sodium flow environment. A device that would enable easy control of the developed pressure and the flow rate with good maintenance and safety characteristics is needed in performing the simulation.

The pump is considered to generate sodium circulation satisfying those conditions because, structurally, it does not have an impeller, which directly contacts the working sodium with a strong chemical reaction property and can control the flow rate by varying the power supply. Therefore, the pump with a flow rate of 1380 L/min and a developed pressure of 4 bar is designed and fabricated for the sodium thermohydraulic experiment at the Sodium Test Loop for Safety Simulation and Assessment-Phase 1 (STELLA-1), which is being developed at the Korea Atomic Energy Research Institute.

As one of the steps to estimate the pump characteristic, the magnetic field is analyzed because the magnetic field distortion causes the end effect at both ends of the pump to influence the developed pressure and the flow stability of the pump. The magnetic field distribution in the narrow channel and the inner core of the pump is calculated by numerically solving Maxwell's equations using ANSYS Maxwell, which is commercially used as a numerical analysis code.

PARADOXALE INCREASING OF MAGNETIC FLUID SUSCEPTIBILITY IN STRONG FIELDS.

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Nowadays, the Langevin theory is the starting point for describing properties of magnetic fluids - colloidal solutions of magnetics. According to this theory, the average magnetization of particles is determined by the balance between the orienting action of the field and the disorienting thermal fluctuations. When the magnetic field increases the magnetic moments of the dispersed particles line up in one direction and the magnetic susceptibility of the fluid decreases steadily. In case of an alternating field, it is necessary to take into account the final time of relaxation. However, in general, the picture remains the same - increasing of field amplitude should reduce the susceptibility of the magnetic fluid. In this paper, we present the results of measuring the dynamic susceptibility of a magnetic fluid as a function of the amplitude of the alternating field. It turned out that the magnitude of the susceptibility (the ratio of the amplitude of the first harmonic of the magnetization to the amplitude of the probe field) in certain cases increases with the field amplitude. This phenomenon is observed on samples of a magnetic fluid containing large particles, and for field frequencies exceeding the critical one. In our experiments we used samples of a magnetic fluid on basis of magnetite particles which were stabilized with oleic acid in kerosene. Dispersed magnetite was obtained by chemical condensation. By centrifuging the initial fluid, light and heavy fractions were isolated. For the experiments, four samples of a heavy fraction of different concentrations were prepared. The first three samples differed in concentration from each other by approximately two times. The concentration of the last sample was close to the limiting one and differed by about one and a half times from the previous one. Two samples of the initial fluid and light fraction of extremely high concentration were also prepared. The dynamic susceptibility measurements were performed by a mutual inductance bridge with a thermostating system. The measured field dependences of the dynamic susceptibility of the heavy fraction samples were drawn on the Cole-Cole diagram. The curves represent a family of smooth arcs that merge into one at high frequencies. There is one peculiarity of the diagram, the interpretation of which is not yet clear. The extensions of all curves intersect the abscissa axis at a single point other than zero. It turns out that the increase in the amplitude of the field does not in any way affect the high-frequency limit of the susceptibility of the magnetic fluid. Even more unexpected is the transformation of the high-frequency part of the Cole-Cole diagrams. It turned out that there is a frequency of the alternating field at which the magnitude of the dynamic susceptibility at the first harmonic is practically independent of the field amplitude. Above this frequency, the susceptibility of the liquid increases with the field. Moreover, on the Cole-Cole diagram, the points corresponding susceptibility are displacing along the susceptibility curve corresponding to the field of the small amplitude. The growth of the susceptibility with the field was observed precisely on the samples of the heavy fraction. That is, the presence in the sample of large particles paradoxically affects its high-frequency susceptibility. On concentrated samples of the initial fluid and light fraction, only a slight change in the susceptibility was found. The increase in dynamic susceptibility was observed on all the samples of the heavy fraction, but in different degree. At the sample of the lowest concentration, the susceptibility varied by only ten percent. The increase in the susceptibility of the most concentrated sample was 2.2. That is, in our case interparticle interactions provide an additional one and a half increase in dynamic susceptibility at high frequencies. Crystallization of the carrier fluid weakens the growth of dynamic susceptibility in the field. In this case, obviously, it is not possible to orient light axes of magnetization of particles by the field.

ENERGY AND SPECTRAL CHARACTERISTICS OF MHD VORTEX FLOW

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The influence of external alternating magnetic field on the molten metal leads to initializations of the flow in the medium. The external magnetic field generates eddy currents in conductive medium. The interaction of these currents with initial magnetic field create the driving force. In lots of technical applications the area of magnetic field action are localized because of the restricted size of electromagnets. This method of electromagnetic force generation found wide application in industry. Contactless generation of the flows in liquid metals are used in contunious casting process (e.g. production of cylindrical alluminium ingots [1]). In the present work the flows of liquid gallium allow in thin rectangular layer under altrnating localized magnetic field are investigated. The thikness of the layer is much smaller than its planar sizes. The C-core inductor is used for electromagnetic force generation. The experimental setup consists of the cell made from plexiglass. The cell is filled with liquid gallium allow and placed in the gap of C-core inductor.The number of large-scale vortexies are determined by the location of inductor's poles. The first configuration of the setup corresponds to the steady two-vortex flow. The characteristics of the flow that are created by the inductor's coils under currents 1 up to 10 A are invesigated. The small amplitude velocity pulsations with the frequency of 4 Hz against the background of steady flow are found by the use of PP. The measurements occurred by ultrasonic Doppler Velocimeter (UDV) and PP demonstrate similarity in kinetic energy evolution. The UDV sensor was located the such way that the areas of ultrasonic and PP measurements were coincided. The main characteristic of the flow was mean kinetic energy of the flow. The main portion of the two-vortex flow energy are in steady vortexies (mean flow). The energy of pulsations is small portion of the full kinetic energy. The two-vortex flow becomes unstable and pulsations violate main steady flow under the current of 8 A. This leads to decrease of the mean energy and increase of pulsation energy. The second configuration corresponds to the oscillatory four-vortex flow. The four-vortex flow is unsteady. Due to vortexies change their scale and rotation rate, the main characteristic of the flow was the kinetic energy of velocity pulsations. The difference between the full kinetic energy of the flow and the energy of pulsations is insignificantly. So the pronounced pulsational flow exists against a background of weak stationary motion. The largest spread in energies dependencies from one experiment to anouther observed in the range of currents 5–7 A. Apparently, in this range there is a qualitative rearrangement of the structure of the velocity field, which is manifested in a decrease in the kinetic energy and in a change in the frequency of pulsations. It should be noted that the dependence of energy on the frequency of the external magnetic field is non-monotonic. The pronounced oscillations of the mean energy against the background of the general energy increase with an increase in the frequency of the magnetic field from 25 to 105 Hz are observed. Thus, the energy characteristics of two types of vortex flows were investigated. The obtained dependencies are consistent with the results of earlier studies [2]. So they expand information about the structure and characteristics of the flow. This work is supporting by the RFBR grant 17-48-590539_r_a.

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VORTEX FLOW OF LIQUID METAL UNDER THE INFLUENCE OF MODULATED MAGNETIC FIELD

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The production of alloys with specified properties is one of the actively developing areas of metallurgy these days. Stirring of the metal melt during crystallization process leads to an increase in the mechanical strength of the ingots, homogenization in the distribution of impurity inclusions, and the refinement of the metal grains. Usually, the mixing of melts is carried out noncontact due to the influence of traveling or rotating magnetic fields. The alternating magnetic fields generate the eeddy currents in the conductive medium. The interaction of the currents with the initial fields leads to the appearance of an electromagnetic force and, as a consequence, vortex flow. The flows increase the intensity of heat transfer in the melt and smooth the front of crystallization, which can also be useful in the process of growing crystals for microelectronics. Experimental study of processes in the MHD stirers is difficult due to the high melting point and chemical activity of most metal alloys. Numerical calculations allow to optimize the operating parameters and modes of MHD devices, but require verification. Thus, this work is devoted to the simulation of vortex flows generated by the traveling magnetic field (TMF) in a layer of a low-melting metallic alloy. The experimental setup consists of a vertical plexiglas channel filled with a liquid gallium alloy. The channel dimensions are $450 \times 20 \times 75$ mm^3. The channel was placed on a linear inductor of the TMF with dimensions are 480×350 mm^2. The TMF of the inductor created a set of six coils of 170 turns each. The inductor coils were powered by a three-phase current source Pasific Smart Source 360 ASX-UPC3. The current source allows to control the form of output signal. The measurements of the flows arising in the metal were occured by the ultrasonic Doppler velocimeter (UDV) DOP 2000, Signal Processing. The four UDV sensors were placed vertically along a narrow channel wall, which corresponds to the restoration of the longitudinal velocity component in several sections along the height of the metal layer. Thus, the dependencies of the maximum flow velocity and RMS velocity pulsations on the strength and frequency of the current were obtained. The influence of low-frequency modulations on the flows generated in the metal was also investigated. It is established that as the strength and frequency of the current increase, the mean velocity of the flow increases according to the law near to linear. The amplitude of the pulsations has weak dependence of the TMF frequency and increases nonlinearly with increasing intensity of the TMF. Thus, it has been established that in this formulation of the problem the control of the TMF frequency is ineffective for increasing the intensity of metal mixing by vortex flows. The greatest intensity of velocity pulsations can be achieved with moderate currents due to structural changes in the flow patterns, rather than the growth of the rotation rate of the vortices.

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SUBCRITICAL REGIMES OF KAZANTSEV DYNAMO-MODEL

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One of the simplest models for a small-scale magnetic field self-generation, which works without such additional conditions as a differential rotation or nonzero helicity of velocity field, is based on the Kazantsev idea. This model describes a growth of magnetic energy in a turbulent delta-correlated flow, if only it can be characterized by large velocities and small magnetic diffusivity, in other words if the flow is defined by a large enough magnetic Reynolds number. Such supercritical regime, when Reynolds number is larger than some critical value, is well-known and studied by numerical, analytical and asymptotic approaches. However, the large Reynolds numbers, usually observed in astrophysics, are hardly reached in the laboratory experiments or in the modern liquid-metal devices. From a traditional point of view the subcritical regimes with small Reynolds numbers should describe a process with exponentially in time decreasing magnetic energy, thus these subcritical cases do not usually attract the special attention. Nevertheless, this point is totally incorrect. In our presentation we show the results of subcritical studying of dynamo in mirror-symmetric and asymmetric flows (the idea of subcritical regime was suggested by Ja.B.Zeldovich). We demonstrate and speculate the possibility of local in time magnetic energy increasing in subcritical velocity fields, the subcritical energy growth with external support, the subcritical small-scale dynamo realized by a large-scale Steenbeck-Krause-Raedler generation and other subcritical cases. We show a dependency of growth rates for such processes on magnetic Reynolds numbers and discuss the moment of a subcritical regime transformation in a supercritical one.

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CHIRAL MAGNETIC LIQUID CRYSTALLINE SUSPENSION IN A ROTATING MAGNETIC FIELD

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The dilute suspensions of ferromagnetic particles based on cholesteric liquid crystals (CLC) are called ferrocholesteric liquid crystal. They have a spontaneous helical orientational structure which can be governed by various external fields. The imposing of a magnetic field perpendicular to the helix axis of a ferrocholesteric induces a rotation of magnetic particles in the direction of the field, which deforms its helical structure. The growth of magnetic field strength leads to an increase in the ferrocholesteric pitch. At a certain critical field, the pitch goes to infinity and a ferrocholesteric - ferronematic phase transition occurs.

We have studied the dynamics of the helical orientational structure of a ferrocholesteric liquid crystal in a rotating magnetic field, which is directed orthogonally to the axis of the ferrocholesteric helix. The coupling of magnetic particles with liquid-crystalline matrix is supposed to be soft (i.e., the angle between the director and magnetization can change under the influence of a magnetic field) and planar (i.e., in the absence of external field the director is parallel to the magnetization). The nonstationary equations of motion of the director and the magnetization of ferrocholesteric liquid crystal in a rotating magnetic field have been obtained. We have analyzed the limiting case of rigid coupling between a CLC-matrix and magnetic particles. In the approximation of weak magnetic field, small and large angular velocities we have obtained analytical expressions for the pitch of the ferrocholesteric helix.

We have studied numerically and analytically the case of the stationary rotation of the ferrocholesteric structure. This regime is characterized by the rotation of the ferrocholesteric helix at which the director and the magnetization follow the orientation of the magnetic field with the same angular velocity with a constant phase lag. An orientational phase diagram of a ferrocholesteric — ferronematic transition has been calculated for different values of material parameters of a liquid-crystalline suspension. We have shown that an increase in the angular velocity of rotation reduces the magnetic field strength of the transition. For certain values of the magnetic field strength the increase of the angular velocity can lead to a sequence of reentrant orientational ferrocholesteric — ferronematic — ferrocholesteric transitions. The dependence of the pitch of the ferrocholesteric helix on the angular velocity of a magnetic field at various magnetic field strength and material parameters of a suspension has been numerically obtained. It is shown that an increase in the rotational frequency or the parameter of the effect of the magnetic field leads to a decrease in the transition field to the ferronematic phase.

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MAGNETIC BEHAVIOR OF A NEMATIC LIQUID CRYSTAL DOPED WITH SPIRAL MAGNETIC PARTICLES

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The orientational structure of a nematic liquid crystal (NLC) doped with spiral magnetic particles in a magnetic field has been theoretically studied. We have assumed that chiral particles are made of a ferromagnetic material and have magnetic moments. To describe the liquid crystalline suspensions, we have used the continuum approach on the basis of generalized thermodynamic potential (free energy) of an NLC, taking into account a small amount of spiral magnetic particles embedded in an NLC-matrix.

We have proposed the new form of the contribution to the free energy density due to chiral magnetic impurity in a suspension. By minimizing the free energy of a suspension, the system of equilibrium equations that determines the orientations of the director and the magnetization have been obtained. We have shown that in the initial state, that is, in the absence of external field, the orientational structure of a nematic liquid crystal becomes spirally twisted in space due to the presence of spiral particles. Such a suspension has orientational properties similar to the cholesteric phase of a liquid crystal. However, unlike a cholesteric liquid crystal, this suspension has a number of unique features. Firstly, the intrinsic pitch of a helical orientational structure of a suspension is directly proportional to the concentration of magnetic impurity and the surface coupling energy, but inversely proportional to the twist elastic module (Frank constant) of NLC host. Secondly, such a soft magnetic material has two mechanisms of the influence of the magnetic field on the suspension: dipole one (the interaction of magnetic particles with the magnetic field) and quadrupole (the influence of the field of a diamagnetic NLC matrix).

We have obtained the analytical expression for the helical pitch of a suspension in a weak magnetic field and for a strong coupling between the liquid crystalline matrix and magnetic particles. In this limiting case the pitch of the helix is proportional to the square of magnetic field strength. In the absence of segregation effect at the homogeneous distribution of magnetic particles in NLC we have obtained analytical solution for the critical magnetic field strength of the phase transition from the initial helical state to the untwisted state. The corresponding phase diagram of the transition has been calculated.

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IMPACT ON IMPURITIES IN A FLAT MHD DUCT

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Cleaning of ores and molten metals is an actual and economically important metallurgical problem. Purified metal has improved properties: mechanical strength and uniformity of properties. In an electrically conductive medium, external electric and magnetic fields are capable of creating a volumetric force, leading to a change in the effective weight of the liquid. In this case, the electromagnetic force does not affect the nonconducting inclusions. Quasi-loading of metal by electromagnetic force leads to the expulsion of non-metallic impurities onto the surface by forces of buoyancy [1]. Experimental modeling of the process of electromagnetic metal cleaning involves a number of difficulties. In addition to high temperatures and chemical activity of working media, the problem of introducing a model impurity of a strictly prescribed chemical composition and proportions into the metal melt is non-trivial. Therefore, the use of aqueous electrolyte solutions seems promising for modeling and studying the separation processes of non-conducting impurities in liquid metals. Thus, it seems natural to investigate the purification process and the effect of additional MHD flows arising under the action of superimposed electric and magnetic fields in model experiments with electrolytic solutions. The experimental setup consists of a separation plexiglass channel placed between the poles of the electromagnet. An electrolyte solution is supplied to the channel inlet under the action of the circulation pump. After the channel, the liquid enters the flowmetering cell through the pipeline, after which it is sent to the measuring cell. Then the liquid supplies to the filling and overflow tanks and again to the circulation pump. Thus, the system forms a closed loop. The concentration of the model impurity is measured in a measuring cell using a computer-controlled reflex camera. The resulting frames were digitally processed to obtain a relative impurity concentration value. Under the influence of the electromagnetic force, the formation of vortex currents in the electrolyte is possible due to the presence of inhomogeneities in the spreading of the electric current due to the design of the channel. This leads to mixing of the medium and a potential decrease in the efficiency of the purification process. Therefore, it is necessary to find a regime corresponding to the best balance between the mechanisms of quasi-loading of the liquid and the generation of mixing flows. The best result shows the effect of a magnetic field of a minimum value of 0.235 T. In this case, the velocity vertical component of secondary flows was approximately 7 mm/s. When a magnetic field of the greatest magnitude 0.695 T was applied, the vertical component of the velocity underwent considerable fluctuations in the range of 5-10 mm/s. In the intermediate variant, when the magnetic field was applied by induction 0.465 T, the decrease in the impurity concentration occurred according to a law close to linear (against exponential decay in previous cases). The vertical component of the velocity was within 10-12 mm/s. This confirms the hypothesis about negative influence of secondary flow on the cleaning process. As a result of the work, the experimental set-up to purify the electrolytic solution from particles of a non-conducting impurity was created. The influence of the magnitude of electromagnetic force applied, as well as secondary flows arising, on the efficiency of the separation process were investigated. It was found that the greatest decrease in the impurity concentration occurred with the minimum value of the applied electromagnetic force. The maximum achieved reduction in concentration is 1/8 of the initial one.

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EXPERIMENTAL STUDY OF AN ELECTROVORTEX FLOW GENERATED BY OPPOSING POINT ELECTRODES IN A VERTICAL CYLINDRIC CELL

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Electrovortex flows (EVF) appear as a result of an interaction between electric current, passing through the conducting medium, and the magnetic field, created by the current itself [1, 2]. EVF take place in some technological devices, such as arc furnace stirrer, which improves crystalline structure of metals [3], channel furnaces for melting metals, liquid metal batteries for electricity storage.

Various methods of electric current supply to the conducting medium can be used for creating EVF. Of interest is the local supply of electric current, that is the supply with a «point» electrode, which is used in many devices, where EVF appear. In example, liquid metal batteries, aluminium reduction cells (including the case of a multielectrode current lead).

There are virtually no study of EVF in problems, where the topology of the emerging EVF contradicts the naturally expected flow for the cavity. It is this problem that is considered in this paper. Namely, the EVF is generated in the cylindrical volume of a liquid metal with a local supply of electric current to the side wall by two opposing electrodes.

In this paper the results of an experimental study of an EVF of gallium alloy, generated in a cylindrical channel by electric current poles localized at the side walls, are presented. With help of an ultrasonic Doppler velocimeter (UDV), the velocity profiles of liquid metal flows are obtained for different electric current values and for different locations of the sensors. The electric current was set in the range from 200 to 500 A. The minimum value of the current was limited by the sensitivity of the UDV.

It is shown that EVF appear in all considered range of the electric current. The flow velocities are relatively low (maximum average bulk velocity is 40 mm/s), but the flows themselves are non-stationary at all considered parameters. The characteristics of fluctuations are determined depending on the applied current. It is shown that even at the lowest currents the flow is not symmetrical and its structure differs from that expected from the geometry of the channel and the location of the electrodes.

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NUMERICAL STUDY OF TURBULENT LIQUID METAL CONVECTION IN INCLINED CYLINDER OF UNIT ASPECT RATIO USING LARGE-EDDY-SIMULATION APPROACH.

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The motion of a liquid in the gravitational field caused by a temperature gradient (thermogravitational convection) is a common phenomenon in many industrial applications. For example, it is found in metallurgy, nuclear power engineering. In particular, it is of interest to study the convection of liquid sodium, which is now used as a coolant in nuclear power plants: temperature pulsations on the channel walls, resulting from convective currents, may lead to metal fatigue and a decrease in the service life of the devices. The latter is especially important in the design of fast neutron reactors. An experimental [1-3] and numerical [4] studies of the liquid sodium convection (Pr 0.01) in cylindrical cavities show that the greatest heat flow between the heater and the cooler occurs in the case of an inclined cylinder. In this paper, the turbulent convection of liquid sodium ($Pr = 0.0094$) in a cylinder with a unit aspect ratio, tilted at an angle of 45 degrees to the direction of gravity, is numerically studied. The temperatures of bottom and top faces were set at 155.6 and 126.2 degrees Celsius respectively, that is the temperature difference between them was of 29.4 degrees and Rayleigh number was $Ra = 1.33 \cdot 10^7$. The Oberbeck-Boussinesq equations were solved by the finite volume method implemented in the open source software OpenFOAM 4.1. Small-scale turbulence was investigated using the large eddy simulation approach (LES), where the Smagorinsky model was used as a subgrid turbulence model. A block-structured mesh, consisting of 2.9 million nodes, was used. To resolve the boundary layer, the node density was increased near the boundaries, according to a given distribution. The cylinder itself was tilted at an angle of 45 degrees to the direction of gravity. The sidewalls were considered thermally insulated. At all boundaries the no-slip velocity conditions were applied. The numerical simulations were performed on the supercomputer Triton of ICMM UB RAS. As a result of numerical simulations, three-dimensional time-averaged fields of velocity and temperature of liquid metal were obtained, as well as pulsation characteristics of these fields. The average integral characteristics of the flow were obtained: the Reynolds number $Re = 16000$ and Nusselt number $Nu = 11.38$. The large-scale circulation (LSC) with an average circulation period of ~ 9 seconds was noted. The profiles of the time-averaged temperature and the y-component of velocity along the vertical axis of the cylinder were obtained, from which the temperature and velocity boundary layers were estimated to be of 0.01 m and 0.003 m respectively. It is shown that at least 5 grid nodes fit into the boundary layer. Calculations were also performed for the regime with $Pr = 0.1$ and $Ra = 10^6$. The average bulk characteristics of the flow agree with a good degree of accuracy with the results of [5], obtained by direct numerical simulation.

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EXPERIMENTAL RESEARCH OF THE MULTISTABILITY OF BODIES WITH A MAGNETIZABLE ELASTOMER

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The problem of the equilibrium shape ambiguity of bodies with a magnetizable elastomer (ME) in a non-uniform magnetic field is investigated in many works. So, the presence of two stable equilibrium positions of bodies with ME at the fixed magnetic field configuration (bistability) is observed experimentally in [1] and is studied theoretically in [2]. However, at the certain arrangement of two electromagnetic coils relative to the body axis, the existence of three stable equilibrium positions (multistability) is possible. This effect is first predicted theoretically in [3]. In the present work, an experiment devoted to the detection of three thin body equilibrium shapes in a non-uniform axisymmetric magnetic field of two electromagnetic coils is considered. For its implementation, the experimental setup is constructed. It consists of the glass tube on which two electromagnetic coils are located, and inside of which the vertical thin body with ME is deformed without touching the walls. The sample is suspended on the adjustable tripod, which allowed to center the body in the tube and to change the suspension height. The coils are connected to the direct current source and are placed in the container with a cooling liquid. The coils current is increased and is decreased cyclically, and the coordinate of the body free lower end is measured. According to these data, the dependence of the sample relative elongation on the coils current is plotted. The currents range existence is found in which three stable equilibrium positions of the thin body with ME are possible. The body length hysteresis at the cyclic quasistatic change of the coils current is shown. It is assumed that the elastic properties of ME correspond to the Mooney-Rivlin model. The elasticity coefficients in this model are determined experimentally by stretching the sample with ME in a horizontal position when the forces are applied to its ends. This technique allows us not to take into account the gravity and assume the sample deformation to be uniform. Thus, the possibility of the multistability of thin bodies with ME in the axisymmetric magnetic field of two electromagnetic coils is shown experimentally.

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TURBULENT MOTIONS IN THE OUTER RINGS OF GALAXIES CONNECTED WITH THE MAGNETIC FIELDS

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The turbulent motions in the galaxies are usually caused by different instabilities and active processes such as supernovae explosions and star formations. A lot of galaxies have also magnetic fields of several microgauss, and they can change the characteristics of the turbulence, too. As for the outer parts of galaxies, such as the periphery regions (situated at distances of several tenths of kpc) and outer rings, the active processes are much weaker. So the role of the magnetic field in generating the turbulence can be much higher. We model numerically the turbulence in the outer rings of galaxies, including the influence of the magnetic field. We show that the field can change the characteristics of the turbulence and give the results for different parameters of the object and initial conditions.

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MECHANICAL PROPERTIES OF MAGNETO-ELASTIC COATINGS

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Magnetic elastomers are systems consisting of a polymer matrix with incorporated magnetic particles. Typically the volume fraction of magnetic particles, whose size varies from several nanometers to some microns, is high enough to respond to an external magnetic field by matrix deformation. This response can be so strong that the material experiences structural changes. Therefore, a magnetic field can be used as a powerful tool for tuning the material structure and its properties.

Magnetic elastomers have gained a lot of attention in the recent years as they serve numerous applications. Among them is a usage of magnetic elastomers as thin coating layers. In this particular case, an external magnetic field can control hydrophobicity of the layer [1]. Chain formation of magnetic particles embedded into the polymer matrix at an applied magnetic field causes not only the matrix deformation, but also leads to a change of the surface roughness. In this contribution, we study mechanical properties of such magneto elastic surfaces in molecular dynamics computer simulations. The surface is modelled using recently developed model of a magnetic elastomer thin coating that captures the dependence of its surface roughness on the elastic properties of the polymer matrix and the magnetic interactions. According to this model, magnetic particles are anchored by several FENE springs to mimic the polymer matrix. We measure elastic properties of the modelled samples in the absence of an external magnetic field as well as at its presence varying its strength. To perform the measurements, we consequentially squeeze samples by an additional wall covering the magneto-elastic layer. In the absence of the magnetic field where the surface is relatively smooth, another deformation is probed: the top wall with attached outermost particles is gradually pulled to stretch the matrix. The obtained results allow us to elucidate how elasticity alters depending on the strength of the external magnetic field along with the internal structure of samples.

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A FOURIER PSEUDOSPECTRAL CODE FOR SOLVING THE MAGNETOHYDRODYNAMIC EQUATIONS WITH INTERNAL HEATING

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Performance and accuracy results for a Fourier psuedospectral code to simulate the incompressible Magnetohydrodynamic equations with internal heating are presented. Muite, Doering and Whitehead have examined scaling laws for the Nusselt number as a function of the Rayleigh number for internally heated infinite number Prandtl incompressible fluid flow on the two dimensional torus and found the possibility of choosing the power of the scaling law depending on the structure of the mean zero internal heating function. It is of interest to extend this work to three dimensions, and to include inertial and magnetic effects. Since such computations are expensive, it is of interest to examine the efficiency of different methods of solving the resulting equations. Cloutier, Muite and Parsani have found that for long time simulation of the Navier-Stokes equations, the implicit midpoint rule can be of comparable accuracy to the Carpenter-Kennedy Runge Kutta scheme. Example software which uses the implicit midpoint rule can be found at https://github.com/bkmgit/PSNM/ in the folder ConvectiveMHD.

MELT SOLIDIFICATION DURING ELECTROMAGNETIC STIRRING: EXPERIMENTAL INVESTIGATION OF A SOLID/LIQUID INTERFACE FORMATION

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Many numerical and experimental researches have shown an efficiency of electromagnetic stirring for aimed change of material's final structure. Different approaches afford considerable fragmentation and homogenization of metal grains and additives. However, same mechanisms, which lead to named effects, could be a reason for increased segregation and alteration of materials mechanical properties. An optimization of the EM stirring is therefore required. It could be provided with increase of the knowledge about the interaction between the stirred melt and the solidification front. The form of a solid/liquid interface is an indicative criterion of intensity of heat and mass transfer processes in the fluid. So the efficiency of EM stirring application, aiming to control the exchange of energy and mass during solidification, can be analyzed through this criterion. Until nowadays, to obtain information about the form of a solid/liquid front were serving only several methods of solidification process visualization. These are, for instance, numerical simulation and X-ray method. A new trend in this area is application of neutron radiography, which principal allows visualizing experimentally the process of an ingot's growth happening in a relative big scale (till 5 cm in depth). We investigated experimentally the process of metal solidification and solid/liquid front formation, influenced by travelling magnetic field (TMF), by application of the neutron radiography method. For that the container with liquid gallium (1.4 kg with melting temperature about 30 °C; the melt volume sizes: height – 12 cm, length – 10 cm, width – 2 cm) was placed on the permanently cooled plate. The vessel had rectangular form to provide 2D images of a solid/liquid interface formation. The ingot growth was influenced by the melt flow, driven with TMF. The field was applied by means of two splinted coils, placed beside both sides of the vessel. Such a disposition of the container and coils made possible to provide an electromagnetic stirring of solidifying melt and to put only the sample on the path of the beam of thermal neutrons. The structure of the melt flow was presented with two vortices, having an oval shape, and dividing the melt volume on two halves along the vessel's axis. An influence of two stirring regimes was analyzed: continuous application of TMF and low-frequency pulsed TMF, provided by interrupting of the magnetic field generation. The pulsed frequency was calculated to be in accordance to the frequency of the main flow circulation. In such conditions appeared a resonant increase of pulsed component of velocity and more developed turbulence. This allowed intensification of a heat transfer in the fluid and, together with mechanical disturbance of moving liquid layers, influence the form of the solidification front. The cases of the electromagnetic stirring were compared to the metal crystallization in the natural conditions (minimal melts' movement). The neutron radiography technique was applied to the investigated process in the following way. The illuminating neutron beam was meeting on its way with the sample, and the neutron flux passing through the material decreased. On the back side of the sample the neutron beam was passing through the scintillator which was converting neutrons to light emission. The light was processed with the imaging detectors covering the illuminated sample area. At the output the shadow images, colored according to the difference between the densities of the solid and the liquid part of the sample, as well as attenuation coefficients of the both phases was visualizing the ingots' development. The obtained shadow images demonstrated that the form of the solid/liquid interface is strongly dependent from the melt flow, driven by the EM force. Comparing to the natural conditions, for ingots, solidified with stirring, the front had a form that is more flat. We stated more homogeneous macro-crystalloid structure for the case of forced mixing. The most pronouncing effect was observed for the low-frequency pulsed application of TMF with resonant frequency.

COMPARATIVE ANALYSIS OF FRACTIONAL RHEOLOGICAL MODELS FOR THE PURPOSES OF DESCRIBING THE MECHANICAL RESPONSE OF MAGNETOACTIVE ELASTOMERS IN MAGNETIC FIELDS

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Magnetoactive elastomers (or MAEs) are composite polymer materials consisting of relatively soft polymeric matrix and ferromagnetic filler particles of different sizes. Such microstructure allows to control various properties of MAEs, for example their shape and stiffness. Due to their high responsiveness to external field-based stimuli, the applications include tuneable mechanical devices as well as cases where elastic subsystem interaction with an external field is important. MAEs exhibit a vast array of interesting physical effects: magnetostriction, magnetorheological effect, magnetically enhanced Payne effect, magnetic and mechanical hysteresis, memory effects etc. This work aims to propose, analyze and compare several fractional rheological models of MAEs. Rheological circuits are phenomenological models used to describe dynamic behavior of a viscoelastic material. We utilize them to model field-dependent viscoelasticity of MAEs. To make rheological circuits more flexible while keeping the simplicity of their forms we make use of fractional calculus and introduce elements with fractional differential stress-strain relations into classical rheological models. In order to obtain data for analysis MAE samples with several different values of carbonyl iron filler concentration have been synthesized. Theoretical model parameters have been calculated via fitting experimental frequency dependences of MAE's dynamic moduli measured under dynamic torsion oscillations in linear viscoelastic regime. It was shown that the simplest fractional rheological models with one fractional element can be used to adequately describe MAE response at weak and for some cases strong magnetic fields where the main contribution to the MAEs mechanical properties comes either from polymer network in the low-field case or ferromagnetic particle aggregates in the high-field case. However, for medium magnetic fields with the expected significant restructuring of the magnetic filler more complex models are needed as using simple circuits (like the Zener model) leads to large errors and inconsistencies in fitting the experimental data. According to the findings presented in this work, two-fractional-element models provide highly accurate results for a wide range of magnetic fields. The main focus of this particular research was the fractional generalized Maxwell (or Maxwell-Wiechert) model with two branches. High effectiveness of this model in describing mechanical response of MAEs for a wide range of external magnetic field values was demonstrated. Possible interpretation of two fractional branches and their fractional order parameters in generalized Maxwell model as representations of MAE components (namely, polymer network and ferromagnetic filler) was proposed.

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ANALISYS OF MELT SURFACE CLEANING POSSIBILITIES BY CONTROLLING FREQUENCY AND SPATIAL DISTRIBUTION OF ALTERNATING MAGNETIC FIELD

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The problem of melt surface cleaning from oxide scab during induction melting is investigated by numerical simulation. The governing equations of the mathematical model describe diffusion of an alternating magnetic field (AMF) into the conducting material, eddy current generation, transfer of the momentum written in terms of stream function and vorticity and taking into account buoyancy and body Lorentz forces, transfer of the heat energy with taking into account joule power generation. The proposed mathematical model has been validated [1] for physical and numerical experiments. Qualitative verifications were made for general flow patterns, for the velocity distributions along the axial and radial directions and at the surface, for the inductor current dependence, and qualitatively was verified the AMF frequency. The proposed model has demonstrated satisfactory agreement. The obtained results of the numerical experiments prove that the most effective methods of flow reversal and surface cleaning are determined by the variations of the AMF frequency. For these methods, the melt surface cleaning flow is AMF-driven. The decrease of the AMF frequency is more efficient than its increase due to the structure of the electrodynamic force curl. The reversal time for the regimes with the varying AMF structure is several times larger than that for the regimes with the varying AMF frequency because the redirection of the AMF-driven velocities is faster than the reversal activated by a far away AMF-driven vortex and buoyancy. The applicability of different cleaning methods is determined by the relative position of the melt and inductor, see for example [2]. The way of surface cleaning version with the increasing AMF frequency may not be realized if the melt horizontal symmetry plane is positioned below the inductor plane at some critical value, as it was observed for the layout with the common bottom; in this case, with the growing frequency, the scab becomes more stable and occupies a wider area. Thus, the frequency decrease to DH 5 is the surest way providing a minimum surface cleaning time; this value does not vary with different position of the melt and inductor. The oxide scab at this stage is considered as solid surface where the no-slip boundary condition for the melt velocity is realized. The viscous stresses in melt boundary layer and in scab are calculated; its dependencies on AMF frequency and inductor geometry are given and described. The results obtained and the mathematical model may be applied for the development of devices allowing to control the fluid motion during the casting process and for engineering of effective technological regimes.

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MODELING OF AVERAGED METAL FLOWS IN AN ALTERNATING MAGNETIC FIELD WITH A RADIATION HEATSINK FROM A FREE SURFACE

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Induction heating is widely used in various fields of metallurgy, in precision manufactures of semiconductor and dielectric elements: induction melting, floating zone melting, metal products surface hardening, crystal growth, optical fibers production. The basic idea is to induction heating using Joule heat of eddy currents induced in a conductive material by an alternating external magnetic field. The power released by eddy currents leads to the material local heating. A mathematical model is developed in work [1] describes the motion of a metallic melt in an alternating non-uniform magnetic field, the estimates were made, it is possible to split the complex magnetohydrodynamic problem into two subproblems: the problem of magnetic field diffusion, where the distribution of external and induced magnetic fields and currents is determined, and the problem of heat and mass transfer with a known distribution of volume sources of Joule heat and the Lorentz force. The melt motion in an alternating magnetic field is determined by buoyancy which is caused by the inhomogeneity of the temperature field due to metal body heating at the lateral surface predominantly and intensive radiation heatsink from the surface. On the other hand, the motion of the melt is affected by the body Lorentz forces arising when a conducting medium moves in a magnetic field. The main parameters of the problem are the dimensionless magnetic field diffusion parameter $D_H = \mu\mu_0\sigma R^2\Omega$ and the Hartmann number $Ha = \sqrt{\mu\mu_0 H_0^2 R^2/(\rho\nu^2)}$, which determine the structure of the magnetic field of induction currents, and consequently, the distribution of heat sources and Lorentz volumetric forces, and intensity of flows. Here μ is the permeability, μ_0 is the magnetic constant, σ is the conductivity, R is the characteristic dimension of the conductor (internal radius of the crucible), ω is the cyclic magnetic field frequency, H_0 is the magnetic field strength, ρ is the melt density, ν is the kinematic viscosity. The solution of the problem of finding the magnetic field is given in paper [1]. The correctness of the proposed mathematical model is proved by comparison the results of calculations with experimental data [2, 3] and results of calculations of other authors [4]. In the work [5] the applicability of the numerical algorithm is shown for solving the heat conduction problem in a solids with body heat sources, for radiative cooling of solids and also for using averaged laminar model for the description of the nonstationary turbulent heat and mass transfer realized in experimental installations. The results of this approach correlate with the calculations, executed with the help of turbulent LES-model. Comparison of the numerical results with the experimental data of other authors allows us to conclude that the proposed model is suited well for qualitative and with some caution for the quantitative analysis of the convection of a metallic melt in a high-frequency magnetic field. Based on the results of computational experiments the maps of the stable flows regimes in the parameter plane DH-Ha, It is shown that for Hartmann numbers lesser than a certain value of the flow are of a free convective nature, In this case, the amplification of the magnetic field slows the movement of the melt. For large values Hartmann numbers the structure of the flow is imposed by the body distribution of the Lorentz force. The frequency dependence of the loss of sensitivity to the melt properties characterized by the Prandtl number ($Pr = \nu/\alpha$, α — thermal diffusivity) is found.

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SELF-ASSEMBLY OF BIDISPERSE SUPRACOLLOIDAL MAGNETIC POLYMERS

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Currently available polymer materials can exhibit controlled responses sensitive to a wide range of parameters (temperature, electromagnetic radiation, catalysts). In order to obtain a significant magnetic response, polymer materials have to incorporate solid colloidal particles with magnetic properties. Available experimental techniques allow to create linear structures of magnetic colloids permanently stabilised with polymer crosslinkers, forming magnetic polymer chain-like structures at a supracolloidal scale. Such structures, that we call supracolloidal magnetic polymers (SMPs), have a barely explored potential to be the basis of many interesting technological applications, like magnetically controlled microfluidic devices, sensors and actuators or magnetic fluids with enhanced properties. Despite this interest, the study of SMPs is still in a very early stage.

One important aspect not yet addressed in the theoretical study of SMPs is the impact of the polydispersity of their magnetic particles on their properties. This work is devoted to the dependence of the equilibrium structural properties of SMPs on such polydispersity. Following the seminal theoretical work on the effects of polydispersity on the properties of ferrofluids [A. O. Ivanov and S. S. Kantorovich, Phys. Rev. E, 2004], we consider a bidisperse model as a first approximation to a polydisperse system. We study four types of magnetic polymer chains: consisting of only large particles (0); with all large, but one small particle located at one chain end (1); with two small particles at the chain ends (2); with three small particles, two of them at the chain ends and one in the middle (3). Using replica-exchange molecular dynamics simulations, we study the radius of gyration and magnetic moment of a single linear SMP in a wide range of temperatures. We observe that the presence of even a little fraction of small particles in the chains significantly affects their structural behaviour. With the addition of small particles at the ends of the chains (configurations (1) and (2)), the radius of gyration is larger than the corresponding to the monodisperse system (0). On the contrary, the presence of a small particle in the central part of the chain tends to decrease the radius of gyration with respect to the same reference system. These results evidence the importance of polydispersity on the equilibrium properties of SMPs and pave the way to more detailed studies.

HELIX UNWINDING IN CHIRAL LIQUID CRYSTALS DOPED WITH MAGNETIC PARTICLES

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Suspensions of nanoparticles in liquid crystals (LC) attract a great fundamental and practical attention. Particularly interesting are suspensions of ferromagnetic (FM) particles in cholesteric liquid crystals (CLC) called ferrocholesterics (FC). Introduction of FM particles in a CLC results in significant increase of magnetic susceptibility and reduction of magnetic field of unwinding of the helical structure. FC is characterized by two mechanisms of interaction with the external magnetic field: the quadrupolar one (regarded with the influence of magnetic field on the diamagnetic CLC-matrix) and dipolar one (caused by the influence of magnetic field on the ferroparticles), whereas the pure CLC has only quadrupolar mechanism. We consider the so-called compensated ferrocholesterics, which contain the equal volume fractions of particles with oppositely aligned magnetic moments. We assume that magnetic particles are embedded into the CLC in such a way that their long axes are oriented perpendicular to the local director of the CLC. Such a composite system is LC analog of a helical antiferromagnetic. For CLC with positive diamagnetic anisotropy the orientational mechanisms compete with each other. We consider the case of soft orientational coupling between the CLC and embedded magnetic particles. In the framework of continuum theory we study the unwinding of the helical structure (ferrocholesteric – ferronematic phase transition) under magnetic field directed perpendicularly to the helical axis. The dependence of the transition field on the material parameters is found. Our results show that in order to decrease the value of operated field, the dipolar orientational mechanism has to predominate over the quadrupolar one. Attention is paid to the effect of particles redistribution under applied field. The average magnetization of FC and magnetic susceptibility as functions of a field and material parameters are also stidied. We show that in the unwinding structure FC has ferrimagnetic order of the particles. We compare the obtained results with the case of ordinary, i.e., non-compensated FC, which is an analog of liquid-crystalline helical ferromagnetic, and show distinctive differences in the orientational response on applied field and the field behavior of the pitch of helical structure.

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THERMOGRAVITATION CONVECTION INFLUENCE ON HEAT TRANSFER IN THE CHANNEL MODELING THE ACTIVE ZONE OF THE BREST NUCLEAR REACTOR

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The basis for the designing of atomic and thermonuclear reactors is the thermohydraulic calculation of the core, carried out with the machine codes, working with the existing theoretical models, which do not take into account the effect of thermogravitational convection on heat transfer. Our investigations show that this is not true and the presence of thermogravitational convection can not be ruled out when calculating heat exchange of liquid metals. The aim of the work is to determine the significance of thermogravitational convection contribution on heat transfer in a complex channel simulating the fuel assembly of a BREST nuclear reactor by comparing the results of experiments with upward and downward flow. To carry out the experiments, the unique scientific facility «Mercury MHD-stand» is used, located in MPEI. Hinged probe is used as a measuring one, designed at the Thermophysics department of the MPEI. Most metals have a high melting point, which makes more economical using mercury to conduct experiments, since it is in the liquid state at normal temperatures. It is used hinged type probe with mounted microthermopair at the far end for measurements. The experimental channel is a complex shape with three rounded parts simulating fuel rods. They equipped with nichrome ribbons for electric heating. To ensure the possibility of three-dimensional studies of temperatures in the channel, an element is introduced that simulates a fragment of the distancing grid between the fuel rods and is able to move along the channel in the longitudinal direction. The length of the channel is 1 m. The experimental facility is equipped with a specially created automatized system (ASNI) on the basis of National Instruments and HewlettPackard equipment. The facility is connected to the instrument racks, where switches and voltmeters located, with the measuring and control channels. The HewlettPackard equipment rack is connected via the GPIB instrument interface to the National Instruments PXI system. The whole ASNI can be divided into four subsystems. Subsystem 1 measures the voltages and currents of the heaters, subsystem 2 measures the temperatures and heat meters of the stand, subsystem 3 manages the coordination mechanism of the probe and subsystem 4 provides measurement of probe thermopair. All measurements are transferred to the personal computer mounted on the stand. A special program is installed on this PC and can obtain and operate all data and systems of the stand. The coordination mechanism of the probe consists of two stepper motors and two indicators. Indicators' measurements are transferred to the PC of the stand and the program immediately fixes them. Stepper motors are also controlled from the program interface. The image of investigated section of the channel is covered by a grid using the program. While approaching the wall, the mesh nodes becomes more condense in order to simplify finding the wall by temperature profile fracture. The approach to the wall is carried out along the normal to minimize the sliding of the probe along the wall. In order to ensure of the wall touch, measurements are also made in coordinates that clearly extend beyond the internal area of the channel, while the probe rod is elastically bent and in fact the measuring sensor touches the wall. During the first series of experiments, data were obtained for upward flow with numbers $Re = 20000 \div 40000$ and heat flow $q_c = 30000 \div 40000$ Wt/m^2. The initial data is presented in table form. But the tables are very large and hard-to-read, so for clarity we visualize the data. A special handler for two-dimensional data sets is used for this task. The program prepares the obtained table of experimental data in a form convenient for read, and also constructs maps of the temperature and temperature pulsations in the channel, and graphs of the wall temperature and temperature pulsations distribution along the perimeter of the wall, and the temperature profiles and temperature pulsations from the wall to the flow center. Later it is planned to obtain results for similar flow regimes, but for downward flow.

PULSED FLOWS OF LIQUID SODIUM IN A TOROIDAL CHANNEL: GRID-INDUCED TURBULENCE

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The method of generation of turbulent flows in liquid metals by excitation of pulsed flows in a toroidal channel has shown its effectiveness for studying the intense screw [1] and free [2] turbulent flows. The experimental setup used in these studies makes it possible to obtain turbulent flows of liquid sodium with maximum Reynolds numbers $Re \approx 3 \times 10^6$ and $R_m \approx 30$ (free channel). In our work, this setup was used to study MHD turbulence behind a grid - a traditional object for studying turbulence generated on a given scale. Metal grids with a fixed spacing, located across the flow, are widely used as turbulence generators on pipe flows. The grid period, being the natural scale of the excited turbulence, determines the Reynolds number, which is proportionally smaller than in the case of an empty channel. Moreover, the recurring flows of the liquid sodium through the grid (up to their full attenuation) lead to repeated turbulent excitations. Thus, the characteristics of turbulence in the flows of liquid sodium can be significantly changed by varying the intensity of the excited flow and the period of turbulent grids.

The channel is equipped with sensors for measuring the liquid sodium velocity and the intensity of the magnetic field in the vicinity of the channel walls. An important measuring component of the setup is the phase measuring system, which is a transformer with toroidal coils and the sodium channel served as its core. With the help of this system the effective electrical conductivity of sodium in the channel and thus the magnetic viscosity of the turbulent sodium flow (beta effect) can be estimated from the phase shift between the primary winding current and the EMF in the secondary winding.

During the experiments, the correctness of the phase electrical conductivity measuring method was verified by a comparison with electrical conductivity estimated by electromagnetic pulses logarithmic decrement. It was shown that grids turbulence generates a quasi-stationary turbulent flow, which is not observed in the case of an empty channel. In the examined range of the initial flow parameters ($10 - 45$ rot/s - the initial channel rotation speed and $0.3 \div 1$ s - the braking time), the maximum change in the electrical conductivity of liquid sodium caused by turbulent pulsations does not exceed 3%. Such a small value as opposed to the case of an empty channel (about 30%) can be explained by a decrease in the characteristic turbulence scale and a reduction of the pulsation amplitudes due to the grid hydraulic resistance. The values of Rm calculated from the velocity pulsations and the grid period are approximately 10 times smaller than in the case of an empty channel.

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INFLUENCE OF SHOCK WAVE ON A WEAKLY IONIZED GAS

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The basic principles of nonlinear ion-acoustic waves formation in weakly ionized gas subjected to the shock wave of neutral gas were investigated by the numerical and analytical methods. The ion-acoustic approximation were employed to describe the plasma component of charged gas. Within a such approach the ion-acoustic waves arise via the collisions of charges with the neutral particles only. For numerical simulation the initial and approximate boundary conditions for non-stationary problem are determined in assumption that the solution of runaway wave type can be found. The strong anomalous nonlinear effects appear in this case. The competitive action of nonlinearity, dispersion and dissipation at the formation of specific plasma "condensations" and "rarefactions" is shown. In narrow range of the shock wave velocities the anomalous relaxation of plasma oscillations occurs behind the front. It appears in the total ambipolar entrainment by the shock wave of charged components. This effect possibly results from the strong nonlinear resonant (in respect to the shock wave velocity) perturbation in the region ahead of front.

LIFTING OF MAGNETIC AND NON-MAGNETIC FLUIDS OVER A MAGNETIZABLE BODY IN A UNIFORM MAGNETIC FIELD

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The motion of samples with magnetic fluid in magnetic fields can be used to design micro devices and to create micro robots [1-3]. A possibility to create a pump using the lifting of the magnetic fluid surface over a ferromagnetic cylindrical body in a uniform magnetic field is discussed in [4] theoretically. In this work, the deformation of a magnetic fluid with variable volume around the spherical magnetizable body in a vertical uniform applied magnetic field (prototype of a pumping or dosing device) is studied experimentally and theoretically. In experiment a fixed volume of a non-magnetic immiscible fluid (polymethylsiloxane) is placed above the water-based magnetic fluid. Fluids are placed in the cylindrical tube. The spherical magnetizable body is on the tube bottom. The volume of the magnetic fluid can change due to source of fluid (a magnetic fluid flows from a large reservoir with a constant fluid level). In experiments, a stepwise vertical uniform applied magnetic field is created by pare of Helmholtz coils. The magnetic fluid surface rises when magnetic field increases, and the non-magnetic fluid rises. Thus, it is possible to dose the fluid if the outflow hole is in the tube wall above the initial level of the non-magnetic fluid and the non-magnetic fluid reaches a hole at some field value, so part of it flows out. In the experiment, the change of the non-magnetic fluid level on magnetic field was measured. The shape of the magnetic fluid with increasing and decreasing magnetic field was recorded. The hysteresis of the contact angle of a magnetic fluid is found. A small difference between the fluids lifting in the increasing and decreasing magnetic field, caused by the hysteresis of the contact angle, is obtained. A calculation method to obtain the equilibrium of magnetic fluid surface shapes, taking into account the surface tension, gravity, and the nonlinear dependence of the magnetization on the magnetic field, is developed. Calculations for the experimental parameters considering the hysteresis of the wetting angle were made. The dependencies of the fluids lifting above the initial level on the applied magnetic field are plotted experimentally and numerically. A good agreement of the numerical and experimental results is obtained.

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STATISTICAL THEORY OF MAGNETIC FIELD BEHAVIOR OF LIQUID CRYSTALS DOPED WITH CARBON NANOTUBES

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We developed tensor model of the mean-field statistical theory for complex nanocomposite material viz. colloidal suspension of a liquid crystal (LC) doped with carbon nanotubes (CNT). A Hamiltonian of the composite with finite attraction interactions between the components of the binary mixture as well as steric repulsion (excluded volume effect) of CNTs was proposed. In such model the orientation of each subsystem has been characterized by symmetric traceless tensor of the second rank constructed on the unit vectors along the long axes of LC molecules or CNTs. With the help of statistical averaging of this tensors the macroscopic tensors of orientation for the LC molecules and impurity CNTs were able to be introduced. On the base of proposed Hamiltonian we calculated the statistical integral and the free energy of the suspension. We obtained the set of equations for the orientational state of a suspension in the magnetic field that describe the temperature and the field dependence of the order parameters of the suspension components. We found the analytical expression for the critical concentration of CNTs in the suspension, above which the appearance of isotropic phase becomes impossible due to steric repulsion of the impurity even in the absence of a magnetic field. We also found the analytical expression for the Curie-Weiss temperature, below which the isotropic phase becomes absolutely unstable in the case when CNT concentration is lower than the critical one. The dependences of the order parameters of a LC matrix and the CNTs as functions of temperature for different values of material parameters and magnetic field were studied. We have studied the transition temperature from the ordered nematic state to the paranematic state, and the jumps of the order parameters at the phase transition point as functions of the coupling energy of subsystems, the concentration and the size of CNTs.

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CONDENSATION MODE INSTABILITY IN PARTIALLY IONIZED HEAT-RELEASING PLASMA

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The recent observations of the interstellar medium (ISM) has shown that small-scale structures of the ISM are ubiquitous. The formation of such structures is unlikely to be the result of a gravitational instability since their size is much smaller than the Jeans length. The other possible mechanism that may lead to the small-structures formation in the ISM is the thermal instability. The theory of thermal instabilities was laid by Field in his pioneer work [1]. He showed that the condensations are emerged under the condition of the so-called isobaric instability which is the one type of thermal instabilities. The mechanism of the condensations growth is the following. If the cooling becomes efficient as the temperature decreases and at the same time the fluid is contracted, the condensations grow. Importantly, the critical length scale of isobaric instability is smaller than that of the Jeans instability. So, the system can be thermally unstable even when it is gravitationally stable. The formation of ISM structures such as molecular clouds is considered as follows [2]. The hot ionized clouds become cold due to the isobaric instability that leads to the decrease of the degree of ionization of plasma. Partially ionized plasma in an external magnetic field can not be described using one-fluid model, since the ion component is directly affected by the magnetic field, whereas the neutral component is not. In papers [2-5], partially ionized plasma in an external magnetic field is described using the two-fluid model. This approach assumes that ions and electrons make up an ion-electron fluid, while the neutrals form separate fluid. The study of condensations growth [2] using the two-fluid model was carried out with the number of assumptions such as weak degree of ionization, identical temperature of ion-electron and neutral components. Moreover, the description of magnetoacoustic waves propagating in such medium was carried out only for the direction of perturbation propagation perpendicular to the external magnetic field. In this work, we has obtained the linear equation describing the dynamics of small perturbations in the partially ionized heat-releasing plasma in an external magnetic field. The study was carried out for arbitrary degree of ionization. The dispersion relation describing magnetoacoustic and condensation modes has been obtained as well. Analyzing the dispersion relation, we has obtained the amplification condition of condensation mode and calculated its temporal increments over the wavenumber for various degrees of ionization and magnitudes of an external magnetic field.

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STOCHASTIC EXCITATION OF LARGE-SCALE NONAXISYMMETRIC FIELD IN SOLAR TYPE DYNAMO

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The random variations of the kinetic helicity and the α effect are often considered as the main source of the long-term variations of the solar cycle. Generally, it is expected the hemispheric α effect varies in a range of 10 to 20 percent of magnitude. In this case, the nonaxisymmetric quadrupole perturbations of the α effect can have twice as high of the hemispheric variations of α. This effect is usually ignored in stellar dynamo models. Using the nonlinear mean-field dynamo models we show that such nonaxisymmetric random perturbations of the α effect can maintain the large-scale nonaxisymmetric magnetic fields in the solar-type $\alpha^2\Omega$ dynamo. We find that in case of the solar-like star rotating with the period of 25 days, the total energy of the dynamo generated large-scale nonaxisymmetric magnetic field is much less than the energy of the large-scale axisymmetric magnetic field. However, the generated nonaxisymmetric magnetic affects reversals of the polar magnetic field. Considering the same time-scale and magnitude parameters of the α effect perturbations for the young solar analog rotating with the period of 6 days, we find that energy of the generated nonaxisymmetric magnetic field is the order of the energy of the axisymmetric magnetic field. We discuss implications of our findings for the theoretical studies the cyclic variability of the Sun and other solar-type stars.

THE FORCE ACTING ON A NONMAGNETIC BODY IN A MAGNETIC FLUID

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The results of measuring the force acting on an aluminum cylinder (a nonmagnetic body) immersed in a magnetic fluid in an external uniform magnetic field are presented in the abstract. The appearance of ponderomotive forces is cause by inhomogeneous «demagnetizing» fields created by the fluid itself. Since the demagnetizing field is maximal at the ends of the cavity and minimal the center, any nonmagnetic body must be pushed out of the central region and pressed against the ends of the cavity by the magnetic part of the hydrostatic pressure. The ponderomotive force dependence on the displacement of the aluminum cylinder relative to the center of the cavity and on the strength of the external field was obtained in the experiment. As might be expected, the ponderomotive force increases with the field strength increase. Near the ends of the cavity with a magnetic fluid, where the field is most inhomogeneous, it reaches a maximum, and in the center of the cavity it is always zero. An unexpected result consists in the detection of large forces repelling the aluminum cylinder from the ends of the cavity at small gaps between the cylinder and the ends. Possible reasons for this abnormal behavior are discussed: the non-Newtonian properties of a magnetic fluid and the thickening of magnetic field lines near the edges of the cylinder.

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AIR CAVITY CONSTRAINED BY MAGNETIC FLUID IN «MAGNETIC VACUUM» OF AN ANNULAR MAGNET

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The article presents the results of an experimental study of capturing, transporting, and subsequent splitting an air cavity into bubbles by a magnetic fluid in the region of 'magnetic vacuum' of an annular magnet. The study was carried out using the acoustomagnetic method. It is shown that the use of the 'non-traditional' region of the magnetic field of an annular magnet expands the possibilities of controlling magnetic fluid when obtaining an isolated gas cavity with a decreased value of the elastic parameter and when splitting this cavity into bubbles. An insight into the dynamics of an air cavity formation in the 'magnetic vacuum' of a magnetic fluid in which the processes of magnetophoresis of microbubbles and fluid breakdown are present was gained. The magnetic field in the vicinity of 'magnetic vacuum' consists of fields with opposite directions, which apparently, creates the conditions for the decrease of elasticity of an air cavity of small size, located in the magnetic fluid. The containment of the cavity in the vicinity of the 'zero' field during its transporting along the tube and fixing it at a given depth is ensured by the magnetic field intensity gradients in the region of 'magnetic vacuum'. The unchanging sizes of the seven-eight bubbles separated first as well as the tendency of a sharp decrease in the size of the subsequent bubbles are presumably related to the peculiarities of the effect of the inhomogeneous magnetic field on the air cavity surface in MF. The resulting bubbles are relatively large in size, which expands the possibilities of controlled by a magnetic field metered feeding of small amounts of gas into reactor.

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A MHD FLOW IN 90-DEGREE BENT CHANNEL

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Investigations of electrically conductive fluid flows in a magnetic field becomes relevant as the plans for construction of research or industrial thermonuclear reactors are realized. Such facilities contains a large number of complex shape pipes, in which liquid metals move in presence of magnetic fields. Experiments in this area are very costly and therefore a large role in research and design is given to numerical modeling. We consider a flow in a 90-degree bend. A fluid is assumed to be viscous and electrically conductive and flows through the channel under action of a pressure gradient. The uniform magnetic field is directed parallel to the outlet branch of the channel. The MHD solver, based on the Nektar++ spectral/hp library, is used for flow simulation. The spectral/hp method combines high accuracy of spectral methods and spatial flexibility of finite-element methods. At present time spectral/hp element methods are being actively developed. The flow was investigated in a wide range of Reynolds and Stuart numbers, with different bending radius. An interesting structure of secondary regimes has been discovered.

SELF-ASSEMBLY IN MAGNETIC FILAMENT SOLUTIONS

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Magnetic filaments are semiflexible polymer-like chains of magnetic nanoparticles permanently crosslinked with polymers, which have been recently shown to be promising building blocks for the creation of sophisticated magnetoresponsive materials. We investigate self-assembly in solution of magnetic filaments with different conformations and lengths. Simple open chains, closed rings and branched structures with “X” and “Y” junctions are used. The work was inspired by the recent findings on the low temperature self-assembly and ground state of dipolar hard spheres. Using Langevin dynamics simulations, we focus on low-concentration solutions of filaments, analysing in detail their self-assembly and macroproperties. Extensive cluster analysis was made using graph theory. Cluster size distribution, amount of additional connections, their distribution and defects were calculated. We define defect particles particles with more than two bonded neighbours and defect cluster, or simply defect, a set of neighbouring defect particles. We introduce two parameters to categorise the defect clusters: s (the number of defect particles in the defect, namely the size of the defect) and w (the number of ways out from the defect). We also compare the structures formed by filament solutions to those observed in conventional magnetic fluids containing non-crosslinked nanoparticles. For example, cluster size distribution has totally different behaviour for ferrofluid and filament's solution. Then we investigate initial susceptibility for different concentrations and different values of magnetic moment. We show that permanent links in the system of magnetic particles and their conformation can dramatically change microstructure and macroscopical response of solution. These results will form the basis for developing theoretical models and provide recommendations for the design of novel magnetoresponsive systems.

INFLUENCE OF THE COPLANAR MAGNETIC FIELD ON THE LIQUID METAL FLOW IN A RECTANGULAR VERTICAL CHANNEL UNDER THE INFLUENCE OF THERMAL LOAD

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Liquid metals (LM) are perspective heat transfer fluids in fusion reactor of the type "tokamak". In fusion reactors of the type "tokamak" flow of the coolant occurs in strong magnetic fields. With this configuration the determining factors influencing the flow are the magnetic field (MF) and thermogravitational convection (TGC). The influence of these factors leads to a change of the characteristics of hydrodynamics and heat transfer. These regularities (MF and TGC) essentially depend on the parameters of the MHD configuration: mutual orientation of the vectors of the flow velocity and of the magnetic field, the shape and geometrical dimensions of the channel, the channel orientation in gravity field, the electrical conductivity of the wall material, the nature of the heating. Therefore, a detailed study of all the possible MHD configurations is an important practical task. Currently it is impossible to talk about the completeness of such data. MHD configuration where a liquid metal circulating in a rectangular channel in a coplanar magnetic field, is implemented in all proposed projects the liquid-metal cooling systems (HCLL, DCLL, WCLL, SCLL) of the core of ITER reactor. This paper presents a model of turbulence suppression by coplanar magnetic field, which was obtained by generalization of experimental data measured by a united mercury facility MPEI-JIHT RAS. It was studied the downward and upward flow of liquid metal in rectangular channel in the presence of coplanar MF. Recall that the coplanar MF differs from the transverse MF in that it acts along the long channel wall but not along the short one. During the experiments, data on the intensity of temperature pulsations at low heat flux values were obtained. This was done in order to get off from the influence of thermo-gravitational convection and to obtain a model reflecting the pure effect of the magnetic field. By estimating of the suppression pulsations degree by the magnetic field, a turbulence suppression model was obtained, which depends only on the regime parameters (number Re and Ha).

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FLOW STRUCTURE OPTIMIZATION AND THE IMPACT ON THE SOLIDIFICATION STRUCTURE

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The adjustment of fine grain morphologies has been approved to be a crucial issue for improving characteristics and properties of cast and wrought aluminium alloys. Several methods are known to achieve grain refinement in solidification processes: add-on of grain refiners, rapid cooling conditions, mechanical or electromagnetic stirring, or ultrasonic treatment. AC magnetic fields provide a contactless method to control the flow inside a liquid metal and the grain size of the solidified ingot. Many studies have shown that beneficial effects like a distinct grain refinement or the promotion of a transition from a columnar to an equiaxed dendritic growth (CET) can be obtained. However, electromagnetically-driven melt convection may also produce segregation freckles on the macroscale. The achievement of superior casting structures needs a well-aimed control of melt convection during solidification, which in turn requires a detailed knowledge of the flow structures and a profound understanding of the complex interaction between melt flow, temperature and concentration field. Previous investigations considered the use of time-modulated AC magnetic fields to control the heat and mass transfer at the solidification front. It has been shown recently under laboratory conditions, that an accurate tuning of the magnetic field parameters can avoid segregation effects and homogenize the mechanical properties. This present study examines the directional solidification of commercial cast and wrought aluminium alloys from a water-cooled copper chill. Rotating magnetic fields were used to agitate the melt. The application of different stirring strategies, e.g. time-modulated magnetic fields, reveals the impact of diverse flow conditions on the resulting macro and micro structure. The solidified structure was reviewed in comparison to an unaffected solidified ingot. Our results demonstrate the potential of magnetic fields to control the grain size and the formation of segregation freckle. In particular, time–modulated rotating fields show their capability to homogenize both the grain size distribution and phase distribution.

THE SPECIFIC FEATURES OF HIGH-VELOCITY MAGNETIC FLUID SEALING COMPLEXES

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The factors, which are insignificant at small velocities, become rather considerable with increasing the shaft surface velocity as far as the magnetic fluid sealing complex (MFSC) is concerned They impact both on the pressure drop restrained by the sealer and on MFS operational resource. To increase the operational capability of high-velocity magnetic fluid seals, it is necessary to take a number of measures for restraining magnetic fluid in the working gap, excluding the impact of centrifugal forces by means of MFSC design changes. The execution of shaft labyrinths is the most effective and widely used method in sealing technology (hydrodynamical, impeller, labyrinth, slot seals, etc.) for reducing the influence of centrifugal forces [1]. Tooth concentrators of the magnetic flux can similarly be made on the shaft but not on the magnetic circuits. In this case centrifugal forces throw magnetic fluid to the tooth top into the region of maximal magnetic field blocking the decrease in the critical pressure drop and magnetic fluid throw-off from the gap. Taking into account the main characteristics of the magnetic fluid sealing complex, the parametres of the magnetic field in the working gap are determined and the mathematical model of interconnected non-linear magnetic and hydrodynamical processes in the MFSC gap is described [2]. The model is calculated by means of the numerical method of finite elements with Comsol package. It is shown that the location of the magnetic flux concentrators on the shaft results in the decrease in the magnetic field drop under the last outer tooth by 10It is also shown that the location of magnetic flux concentrators on the shaft reduces the value of the vortex velocity in the end part of the sealer, the directions of the vortex and the magnetic induction vector are opposite each other. The results of multi-phycal modeling were used to design the magnetic fluid sealing complex for the coke gas-blower.

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DYNAMIC MAGNETO-OPTICAL EFFECT CAUSED BY PARTICLE–MATRIX COUPLING IN FERRONEMATICS

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Dispersions of ferromagnet nanoparticles in nematic liquid crystals (NLCs) — the so-called ferronematics (FNs) — are unique and remarkable composites. Even in small concentrations, the presence of nanoferromagnets endows NLC matrices with a strong magnetic response otherwise absent. Nowadays, when synthesis of stable thermotropic FNs is no longer an exotic event, see [1,2], for example, the detailed investigation of magnetically controlled properties of FNs is the matter of fundamental as well as of practical interest.

However, if to take an overview look at the research work on FNs, it becomes evident that the studies of their equilibrium properties completely dominate over quite a moderate effort aimed at the dynamic properties. Therefore, yet by now the time-dependent magnetic response of FNs is a poorly known subject. Meanwhile, this is an issue of major importance for predicting functioning of magnetically-controlled FN optical cells; and to the same extent it is valid for microrheology of NLC, the carriers of FN systems. Therefore, there is a need for a model capable of describing the behavior of a ferromagnetic particle, embedded in an NLC, under the action of time-dependent field, ac or pulsed. The key feature of FNs is that the particles are orientationally coupled to the matrix, and, due to that, their field-induced motion affects the orientational structure of the matrix changing by that its optical anisotropy both in direction and magnitude.

Formerly [3], we investigated the magneto-orientation relaxation in FNs below the clearing point in the framework of conventional continuum theory ignoring thermal orientation diffusion of the embedded particles. That was an apparent drawback given that in stable FNs the particles are of submicron size and, thus, are subjected to intense Brownian motion. Here the model of dynamic magneto-optical effect in FNs is revised with allowance for the orientation diffusion of the particles. This required us to change from the “hydrodynamic” to kinetic approach. A set of rotary diffusion equations that couples the orientation distribution functions of (*i*) the anisometric fine ferromagnet particles and (*ii*) the molecules of the mesomorphic medium, is derived and solved in the mean-field approximation. This treatment was applied to the problem of phase transition in FNs in Ref. [4], here we extend the framework for a non-equilibrium case.

It turns out that the relaxation process undergoes in two stages. First, the field orients the magnetic moments of the particles. Since the particles are assumed to be magnetically rigid, there arises a torque that strives to mechanically rotate the particles. This magnetic relaxation process has reference Debye-like time τ_m that depends on the strength of the particle–matrix anchoring and is proportional to the particle volume. At the second stage, the liquid-crystalline matrix, being initially uniform, in a pursuit to minimize its free energy, distorts in such a way as to adjust the director field to the boundary conditions on the particles. The matrix response time is given by the conventional estimation $\tau_n = \gamma D^2/K$ with γ being the rotary viscosity of the liquid crystal, K its orientation-elastic (Frank) modulus, and D the reference size of the sample.

To be particular, we consider settling of magnetic and orientational equilibrium in a flat FN layer under a stepwise switching of the field. A constant magnetic field $\mathbf{H}_0$ is imposed in the plane of the layer, and a weak probing field is applied in the same plane perpendicular to $\mathbf{H}_0$. The solutions obtained are used to analyze experimental results on time-dependent magnetic birefringence in a FN layer [5,6].

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STABILITY ANALYSIS OF EKMAN BOUNDARY LAYER FOR THE FLOW BETWEEN PARALLEL PLATES

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A model and numerical framework for the stability of the Ekman boundary layer, a three-dimensional rotating mean flow, have been presented. The linearized Navier–Stokes equations about the Ekman boundary layer take the following form:

$$u_t + Uu_x + Vv_y + U_{(z)}w + 1/R_0 p_x - 2/R_0 v = 1/R_e(u_{xx} + u_{yy}) + 1/R_0 u_{zz}, \tag{1}$$
$$v_t + Uv_x + Vv_y + V_{(z)}w + 1/R_0 p_y + 2/R_0 u = 1/R_e(v_{xx} + v_{yy}) + 1/R_0 v_{zz}, \tag{2}$$
$$w_t + Uw_x + Vw_y + 1/(R_0 E_k) p_z = 1/R_e(w_{xx} + w_{yy}) + 1/R_0 w_{zz}. \tag{3}$$

The system is completed by adding the linearized continuity equation $u_x+v_y+w_z = 0$, where u,v and w are the velocity components, U, V and W are the Cartesian velocity components,p is the pressure and t is the time. Equation (1-3) are dimensionless and the non-dimensionalization is as follows, where $_*$ 2217 values are dimensional $x = x^*/L, y = y^*/L, z = 1/\sqrt{E_k} z^*/L, t = U_\infty/Lt^*, u = u^*/U_\infty, v = v^*/U_\infty, w = 1/\sqrt{E_k} w^*/u_\infty, p = p^*/(\rho\Omega LU_\infty)$, where u_∞ is the geostrophic velocity in the farfield, ρ is the fluid density, L is the wave length, and the dimensionless parameters are $E_k = \Theta/(\Omega L^2)$, $R_e = (U_\infty L)/\Theta$ and $R_o = U_\infty/\Omega L$. The parameter E_k is the Ekman number, R_e is the Reynolds number and R_o is the Rossby number, angular velocity Ω. The governing equations can be modified as a pair of ordinary differential equations

$$(d^2/(dz^2) - \Gamma^2 E_k)^2\Phi - i\Gamma R_0(U'_\infty - c)(d^2/(dz^2) - \Gamma^2 E_k)\Phi + 2\Psi_z = 0 \tag{4}$$
$$(d^2/(dz^2) - \Gamma^2 E_k)\Psi - i\Gamma R_0(U'_\infty - c)\Psi - 2\Phi_z = 0 \tag{5}$$

With the boundary conditions $\Phi(0) = \Psi(0) = 0$, and $\Phi, \Phi_z, \Psi \to 0$ as $z \to \infty$. Equation (4) and (5) with boundary conditions define an eigenvalue problem, where the Eigen functions $\Phi(z), \Psi(z)$ for the eigenvalue c and Γ is the wave number. A finite difference model for the above equations (4) to (5) is developed to analyse the interaction of the Ekman boundary layer with a compliant three-dimensional surface. Of the possible choices of numerical method for the stability problem, such as matrix methods (finite difference, spectral methods), a scheme based on the latter has the best features for stability problems of this type. Asymptotically exact boundary conditions can be used at $= L_\infty$ in a way that preserves analyticity. Analysis of the results includes different Reynolds numbers (Re) and Ekman numbers (Ek) to study the stability of the three-dimensional flow. The results are presented graphically on the compliant surface of the stability of the Ekman layer with respect to the critical Re. The numerical results indicate that on the stability of Ekman-type rotating flows the wall compliance has a very weak effect.

GROWTH OF THE INNER CORE AND MAGNETIC FIELD GENERATION

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The geomagnetic field is generated by the dynamo processes in the liquid core of the Earth. Currently convection has at least two counterparts: the thermal convection due to the cooling of the core, and the compositional convection. The latter one is concerned with the inner core growth. Evolution of the inner core and the thermal state in the core leads to the change of the basic parameters of the geodynamo. From one point of view appearance of the inner core, which accordingly to the models of the thermal evolution of the core took place 1-2Gy ago, can not remain undetected. However paleomagnetic observations do not support this scenario. Firstly, the geomagnetic field was observed early before the start of the inner core nucleation, at least 3.6Ga. Secondly, the proposed by the thermal evolution models age of the inner core does not correlate to any significant change of the paleomagnetic field. We try to examine this situation, using different scenarios of the thermal history of the core. The model includes cooling of the core, crystallisation of the inner core, appearance of the stable regions with the sub-adiabatic temperature profiles at the core-mantle boundary. In fact one has three adjacent regions with two moving boundaries, corresponding to the growing inner core and extending sub-adiabatic region, where the state is governed by the different equations. The model gives distribution of the temperature, thermal fluxes, as well as the coordinates of the boundaries. To resolve these quantities the physical state's parameters: density, pressure, gravity, temperature of the melting are recalculated at every time step. Using this information as well as information on evolution of the day's length one can estimate evolution of the dimensionless parameters of the dynamo equations, such as: the Ekman, thermal and compositional Rayleigh numbers. In its turn, using the scaling laws, these numbers can be related to the dynamic parameters: the Rossby and hydrodynamic Reynolds numbers. Finally, the latter parameter can be converted to the magnetic Reynolds number. Information on the mentioned parameters helps to predict evolution of the frequency of the magnetic fields reversals, magnetic field intensity, angular variations of the magnetic field near the geographic pole.

TWO-DIMENSIONAL MHD WAVE PATTERNS IN THERMALLY UNSTABLE PLASMA

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Thermal instability is considered as one of the main mechanisms responsible for the formation of various spatio-temporal structures in the solar atmosphere and the interstellar medium (ISM). It is realized through the nonadiabatic processes of heating and cooling which are often described by the generalized heat-loss function depending on density and temperature of the medium. The types of thermal instabilities and its mechanism were described in detail in the pioneer study of *(Field, 1965).* In the current work, we consider the only isentropic instability which leads to the amplification of acoustic perturbations in the medium. The studies [1–3] using one-dimensional approach demonstrate that any small initial perturbations in isentropically unstable medium decay into the sequence of self-sustaining shockwave pulses. The shape, velocity, and amplitude of such pulses were described analytically. The evolutionary stability of these structures and the ability to recover their shape after interaction were demonstrated by numerical simulations. However, the one-dimensional analysis of MHD waves is not sufficiently complete. For example, it does not take into account the difference in the direction of the phase and group velocities. The analysis in two-dimensional geometry is therefore required. Thus, we numerically study two-dimensional structures emerging in isentropically unstable plasma. The numerical simulation is conducted using open-source package Athena for astrophysical MHD simulations. We have conducted two series of experiments. In the first one, we have considered the decay of initial Gaussian perturbation of pressure. The numerical simulations have demonstrated that the shape of emerging structures strongly depends on the magnitude of the magnetic field. In the weak magnetic fields (plasma beta is much more than unity), the series of self-sustaining shockwave pulses propagating in all directions is emerged. The one-dimensional slice of these pulses coincides with the results obtained for these pulses in one-dimensional geometry. However, in the strong magnetic fields (plasma beta is much less than unity), the anisotropic patterns corresponding to the slow magnetoacoustic waves are formed. The emerging pulses propagate mainly along the magnetic field. In the second series of numerical experiments, we have considered the evolution of small-amplitude noise in isentropically unstable plasma. Analyzing the results, we have distinguished two stages of noise evolution. The first stage is related to the difference in increments of magnetoacoustic waves along and across the external magnetic field. The strong difference between parallel and perpendicular increments have resulted in the formation of stripe structures elongated along (plasma beta is much more than unity, the strong thermal conductivity along the magnetic field) and across (plasma beta is much less than unity) the external magnetic field. On the second stage, magnetoacoustic waves propagating in all directions reach the final amplitude that results in cellular structure in the case of weak magnetic field. In the strong magnetic field, the waves with maximum amplitude propagate along the magnetic field similar to the first series of numerical experiments. The results of two-dimensional numerical simulation of MHD waves in isentropically unstable plasma thus clearly demonstrate the strong anisotropy of the waves depending on the direction of propagation with respect to the vector of the external magnetic field and its amplitude.

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SIMULATION OF THE RESPONSE OF MAGNETIC POLYMERSOME IN EXTERNAL MAGNETIC FIELD

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Magnetic polymersomes are polymeric vesicles which are built from the amphiphilic copolymer co-assembled with the magnetic nanoparticles (MNPs) [1]. These objects are new actively developed type of nanocarriers which can be applied for magnetic hyperthermia and intracellular delivery. Comprising the magnetosensitive filler from the nanoparticles inside the vesicle membrane, polymersomes are extremely responsive to external magnetic field. Changes in magnetic subsystem of polymersome induced by field — magnetization and MNPs clusters reconfiguration — cause mechanical response and ability of remote transport and release. To obtain theoretical data about possible scenarios of magnetic and mechanical response of single polymersome we propose mesh-based model of three-dimensional elastic capsule-like object. Initially applied for simulation of blood cell flow [2] the approach of immersed in fluid elastic bodies was adapted to construct two shells with several hundred MNPs locked in the space between them. Every shell is in fact assembled from the particles interacting in a special way in the framework of coarse-grained molecular dynamics [3] as well as MNPs couple between each other via dipolar magnetic interaction. The surfaces of spherical (ellipsoidal or another preassigned shape) elastic shells are covered by triangulation nodes, and then each node becomes the center of molecular dynamics particle. In this way, such a meshed object has an internal volume and the elasticity of polymersome shells is defined by interparticle potentials which are particularly tune conservation of equilibrium 1) distance between neighboring nodes, 2) angles between neighboring triangles, 3) area of triangles, 4) area of the whole surface, 5) volume of the whole object. MNPs being simulated as rigid i.e. not meshed particles with assigned dipole moment they "feel" their sizes as well as interact with triangulated surface of elastic membrane. Thereby moving and rearrangement of MNPs locked between shells reflect on deformation of simulated polymersome. Numerical experiments on the model of polymersome with several hundred MNPs subjected to uniaxial magnetic field in constant temperature conditions show elongation of the sample in the field direction. The mechanical effect as it was observed depends on concentration and magnetic moment values of MNPs placed in layer between polymeric shells as well as on elastic properties of the shells.

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THEORETICAL MODELING OF HYBRID MAGNETIC ELASTOMERS

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Magnetic elastomers are one of the most important types of magnetoresponsive materials. They are characterized by large changes in their shape and rehological properties as a response to external magnetic fields [1]. Similarly to magnetic fluids and gels, these are hybrid materials that consist of magnetic nano- or microparticles embedded in a magnetically passive carrier material. Whereas in magnetic fluids the carrier only consists of a liquid background, in magnetic gels and elastomers it includes a viscoelastic polymer matrix. In difference with magnetic gels, in elastomers this polymer matrix contains no liquid background, making them dry materials. These characteristics make magnetic elastomers candidate materials for many technological applications, like tadaptive damping devices, vibrational absorbers, stiffness tunable mounts, soft actuators and micromanipulators, force sensors or artificial muscles.

Even magnetic elastomers are materials not so broadly studied as magnetic fluids, there already exist several approaches to tune their properties. In particular, different concentrations and distributions of the magnetic particles within the matrix have been already explored, as well as different structures and electrical properties of the latter. The magnetic propeties of the particles are also particularly important for the macroscopic response of the material. In most works to date magnetically soft particles have been used to create these materials, whereas the choice of magnetically hard particles is more rare. Finally, the combination of particles of different types and, in particular, with very different magnetic porperties, is an approach even more poorly explored to date. Importantly, the creation of hybrid magnetic elastomers based on such combination is a very promising strategy to obtain a more sophisticated tuning of the properties of these materials.

Here we study theoretically a novel microstructural design for a hybrid magnetic elastomer material that has been synthesized for the first time very recently[2-3]. This design is based on the embedding within the polymer matrix of two types of magnetic particles in different amounts: a low volume fraction of magnetically hard (MH) colloidal particles — typically, ferromagnetic particles of 5-100μm of diameter — and a high volume fraction of smaller, magnetically soft (MS) particles — paramagnetic particles with a diameter typically smaller than 5μm. We study the response of this hybrid magnetic material to external magnetic fields by means of two theoretical approaches. First, we perform extensive computer simulations with a bead-spring model of the system that takes into account the magnetic influence of the MH particles on the MS ones, as well as the mechanical coupling imposed by the polymer matrix on the rearrangements of the particles. Finally, we compare the results obtained from this approach with the ones provided by a continuous magnetomechanical model. In both approaches we focus on a minimal representative volume of the material, consisting of a single MH particle surrounded by a cloud of MS ones and the mechanical coupling between all of them. We analyze the deformations of this elementary volume as a response to the external fields.

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ASYMPTOTICS OF MAGNETIC FIELD IN A WELL CONDUCTING FLUID ON A 2D SURFACE OF REVOLUTION

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We study asymptotics of magnetic field in a well conducting fluid on a 2D surface of revolution. This problem describes behavior of magnetic field in thin layers, forming almost 2D structures with rotational symmetry (like star photosphere). We assume that magnetic viscosity is small and compute asymptotics of natural frequencies, decrements and field amplitudes with respect to this parameter. Mathematically, the problem reduces to the description of the spectrum and eigenfunctions of induction operator on such a surface. For external flows directed along parallels of the surface we compute asymptotics of the eigenvalues in terms of quantization conditions. We prove that eigenvalues (natural frequencies and decrements) are concentrated near certain curves on a complex plane and that the vector of magnetic field is concentrated near parallels of the surface. The direction of this vector in leading approximation appears to be tangent to these parallels. We study separately the surfaces, topologically equivalent to a sphere and to a torus.

INTERMITTENCY OF SOLAR MAGNETIC FIELD AND SOLAR MAGNETIC ACLIVITY CYCLE

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Solar magnetic field consists of two components: large-scale magnetic field which is involved in solar activity cycle and small-scale one. Large-scale component is believed to be supported by solar dynamo driven by differential rotation and a mirror-asymmetric factor responsible for recovering of poloidal field from toroidal one. The nature of small-scale component is much less clear. There are several processes which contributes to small-scale solar magnetic field. This field can be produced as a result of large-scale magnetic field decay, development of solar active regions and sunspots etc. The point however is that a specific type dynamo, so-called turbulent or small-scale dynamo is also possible. Small-scale dynamo is not associated with mirror asymmetry of solar convection and with solar cycle. The question if the small-scale dynamo is active in solar interior or at solar surface is a fundamental physical problem. An elaborated quantification of small-scale magnetic field is required to address this problem. Recent studies show that surface solar magnetic field demonstrates a feature typical for fractal geometry and fractal geometry can be used for small-scale magnetic field quantification. The point is that magnetic field strength extracted from magnetograms strongly depend on resolution: as smaller scales becomes resolved as larger is the estimated magnetic field strength. Wording «fractal magnetic structure» means that the dependence between magnetic field strength and resolution has a power-low range and this power gives fractal dimension of the structure. An investigation of fractal properties of solar magnetic field can be instructive per se and such investigation is the aim of the study. The investigation is devoted to the dependence between observational estimate for solar magnetic field B and resolution D. The aim was to obtain in a reasonably wide range a linear approximation in double-logarithmic scale. The inclination coefficient (quantity k) demonstrate a cyclic variations typical for solar activity cycle. In addition, k depends on magnetic field strength at a given instant. An absolute term (quantity a) demonstrate some cyclic variations however much less pronounced rather k. The physical interpretation of a is that it gives magnetic field strength which corresponds to the maximal resolution accessible in given observations (no averaging). There were a few previous attempts to estimate fractal properties quantitatively. Researchers faced a problem $\sim$2015 the results were qualitatively similar however quantitatively different one from the other. We suggested an interpretation of divergence of estimates for the indices k. All estimates were obtained for different phases of solar cycle and k may be specific for each phase of the cycle, or better to say for each level of solar activity. Our aim is to compare the expectation with observational data. We performed the comparison using the data of SOHO/MDI.

CONFINED INCLINED THERMAL CONVECTION IN LOW-PRANDTL-NUMBER FLUIDS

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We tilt a Rayleigh–Bénard convection (RBC) cell against gravity to investigate the rich dynamics of inclined convection [1, 2]. The inclination changes of the global flow structure inside the cell, which leads to a change of the heat and momentum transport. Especially the heat transport in low-Prandtl-number fluids is sensitive to the inclination angle. Furthermore, we put the focus in our study on slender cylinders of the small diameter-to-height aspect ratio $\Gamma = 1/5$ (cf. recent experiments by Vasil'ev et al. [3] and Frick et al. [4] with liquid sodium (Prandtl number $Pr \approx 0.0089$), which showed that the global heat transport can be several times larger compared to that in RBC in this kind of setup). The study is based on direct numerical simulations of inclined convection to get a detailed insight into the flow structure. Prandtl numbers $Pr \leq 1$ are considered, while the Rayleigh number, Ra, ranges from 10^6 to 10^9. The inclination angle is varied between 0 and $\pi/2$ for each combination of Ra and Pr and an optimal inclination angle, which provides the maximal global heat transport, is determined. Our investigations relate the change of the global heat transport to a change of the flow structure. In inclined convection the large scale circulation becomes important and the formation of two system-sized plume columns, a hot and a cold one, is observed. These plume columns impinge on the opposite boundary layers, which leads to a strong increase in the heat transport [2].

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3D SIMULATION OF PARTICLES TRANSPORT IN DOUBLE SIDE TRAVELLING MAGNETIC FIELD STIRRER

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The thermally activated chemical source of electric energy is one of the alternative sources. Anodes for such batteries are made of lithium–boron composite. The use of electromagnetic stirring in the technology of production of such material makes it possible to obtain a good quality distribution of boron powder in a lithium melt.

In the previous work the model of liquid metal stirring in an elliptical cylinder by a two-sided traveling magnetic field (TMF) was developed [1]. Electromagnetic field, Lorentz forces and hydrodynamic flow are calculated by the finite element method.

In the present report, for good understanding of the stirring process, a 3D Investigation of the particle distribution dynamics in recirculated liquid metal turbulent flow is carried out. Particle motion was described by gravity and Schiller-Naumann drag low. The influence of the TMF inductor electric parameters on the efficiency of homogenization of particles is determined.

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MAGNETO-ORIENTATIONAL RESPONSE OF LIQUID CRYSTAL SUSPENSIONS OF MAGNETICALLY DOPED CARBON NANOTUBES

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It is well-known that liquid crystals (LC) have very low anisotropy of diamagnetic susceptibility. In order to enhance the magneto-orientational response of LC it is possible to dope them with small amount of magnetic particles [Brochard F., de Gennes P. G. J. de Phys. 31 (1970) 691]. Another way to increase the LCs anisotropy of diamagnetic susceptibility is doping them with diamagnetic material with much higher (1-2 order) diamagnetic susceptibility anisotropy like CNTs. It is possible to combine all this methods and dope the LC with CNTs which are covered (functionalized CNTs) or filled (doped CNTs) with ferroparticles.

We have studied magnetic field induced orientational transitions in nematic LC suspensions of magnetically doped carbon nanotubes. For plane layer of a suspension soft planar coupling between CNTs surface and LC matrix and rigid coupling of LC molecules with layer boundaries have been assumed. We have considered the case of positive anisotropy of diamagnetic susceptibility for LC media and CNTs. We have assumed that the dipole moments of the ferroparticles are rigidly bound with the CNTs body and directed along their long axes. In the framework of proposed continuum model there are three orientational mechanisms of field influence on the suspension. Two mechanisms are quadrupole (diamagnetic) and are caused with the interactions of the LC matrix and CNTs with magnetic field. Another mechanism is dipolar (ferromagnetic) one due to magnetic moments interaction of particles with the magnetic field. By minimizing of the free energy functional of LC suspension with respect to the LC and CNTs directors and volume fraction of impurity particles, we have obtained the set of integral equations of orientational equilibrium state. We have shown that there is the critical value of the coupling energy between the LC and CNTs, below which (weak coupling) under magnetic field influence the following transitions take place: initial uniform phase — non-uniform — uniform — non-uniform phase. The first transition has no threshold. The next two transitions between non-uniform and new uniform phase where the LC director is parallel to the boundary plates, and the director of CNTs is aligned parallel to the magnetic field direction have thresholds. If the coupling energy is higher than the critical one (strong coupling) there is only first non-threshold transition to the non-uniform phase. We have obtained the analytical expressions for the threshold fields of transitions between orientational phases as functions of material parameters. We have found that in the case of weak coupling of LC matrix and CNTs, small volume fraction of CNTs is able to change the character of transitions from the second to the first order, i.e., under the influence of magnetic field the distortions of orientational structure of the LC suspension have jump-wise behavior. We have obtained the analytical expressions for the segregation parameter corresponds to the tricritical point.

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CHIRAL ASSYMETRY EVOLUTION IN THE EARLY UNIVERSE FOR THE CASE ALMOST CONSTANTLY HELICITY

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We study leptogenesis and baryon asymmetry generation in plasma of the early Universe before the electroweak phase transition (EWPT), following previuos papers, with accounting for chirality flip processes via inverse Higgs decays and sphaleron transitions which violate the left lepton number and wash out the baryon asymmetry of the Universe (BAU).

We assume that helicity is constant along some interval of time.

MAGNETIC FIELDS OF THE OUTER GALAXY RINGS THAT ARE PERPENDICULAR TO THE EQUATORIAL PLANE

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In the inner parts of the galaxies there are magnetic fields of several microgauss. Their existence has been confirmed by measurements of Faraday rotation of the polarization plane of the radiowaves. The field generation is connected with the dynamo mechanism which is based on joint action of alpha-effect, characterizing the vorticity of the turbulent motions, and the differential rotation that is connected with non-solid body rotation of the galaxy. Some of the galaxies have outer rings that are situated at some distance from the galaxy center. The most likely mechanism for the formation of ring galaxies is the collision of a giant and dwarf galaxies. Another hypothesis of the development of rings is the accretion of matter of dwarf galaxies-satellites. The processes in the outer rings are quite similar: there are differential rotation and turbulent motions, which can cause the magnetic field growth. Previous works showed us that the magnetic field in the outer rings that are situated in the galaxy disc plane is mainly connected with the nonlinear Kolmogorov — Petrovsky — Piskunov wave passing from the inner part of galaxy. We are interested in studying magnetic fields in the outer rings that are perpendicular to the galaxy disc plane. Such rings can cross the main disc, and the main effect is connected with the linear wave passing from the main part to the ring. The typical time for the field to fill the ring is about 10^8 yr, which is quite comparable with the lifetime of such rings. We present the numerical results for outer rings with different values of the parameters.

RESEARCH OF SHAPE DUCT OF INDUCTION PUMP FOR PURPOSE OF PUMPING OUT LIQUID MAGNESIUM

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Long before, an application of magnetohydrodynamic (MHD) devices to a transporting system of liquid metals is implemented. MHD-pumps are applied for forced feed of magnesium alloys through a pipe from bath of a furnace to a filling machine. Therefore, magnesium possesses high chemical activity relate to oxygen. When temperature is achieved the limit point magnesium reacts with oxygen to light up. In the article, influence of duct shape on flow-pressure features is considered. Possibilities of increasing performance of the induction pump an account of improving shape of the pipe are discussed. Attempts have been made to reduce edge effects, push metal from the channel wall and backflows. These researches is basing on the real unit of MHD-pump implemented to Kamensk-Uralsky metallurgical works (KUMZ). Mathematical modeling is realized to commercial software Comsol Multiphysics 5.3 by SST 3-D model of turbulence.

CAN SUPERFLARES OCCUR ON THE SUN?

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Recent data from the Kepler mission has revealed the occurrence of superflares in sun-like stars which exceed by far any observed solar flares in release of energy. Radionuclides data do not provide evidences for occurrence of superflares on the Sun over the past eleven millennia. Stellar data for a subgroup of superflaring Kepler stars are analysed in an attempt to find possible progenitors of their abnormal magnetic activity. A natural idea is that the dynamo mechanism in superflaring stars differs in some respect from that in the Sun. We search for a difference in the dynamo-related parameters between superflaring stars and the Sun to suggest a dynamo-mechanism as close as possible to the conventional solar/stellar dynamo but capable of providing much higher magnetic energy. Dynamo based on joint action of differential rotation and mirror asymmetric motions can in principle result in excitation of two types of magnetic fields. First of all, it is well-known in solar physics dynamo waves. The point is that another magnetic configuration with initial growth and further stabilisation is also possible for excitation. For comparable conditions, magnetic field strength of second configuration is much larger rather of the first one just because dynamo do not spend its efforts for periodic magnetic field inversions but use its for magnetic field growth. We analysed available data from the Kepler mission concerning the superflaring stars in order to find tracers of anomalous magnetic activity. Starting from the recent paper of Kitchatinov and Olemskoy, we find that anti-solar differential rotation or anti-solar sign of the mirror-asymmetry of stellar convection can provide the desired strong magnetic field in dynamo models. We confirm this concept by numerical models of stellar dynamos with corresponding governing parameters. We conclude that the proposed mechanism can plausibly explain the superflaring events at least for some cool stars, including binaries, subgiants and, possibly, low-mass stars and young rapid rotators.

DESIGN OPTIMIZATION OF MHD STIRRER FOR LIQUID SILICON

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In the purification of a silicon melt in vacuum using electron-beam heating [1], the upper layers of melt are cleaned, and feed of impurities from the lower layers having a lower temperature is mainly due to diffusion. Forced stirring with quartz devices is associated with high process failure [2]. At the same time, the stirring efficiency is low and there are reproducible poorly cleaned zones in the purified silicon. To intensify the process, it is proposed to use electromagnetic stirring by a traveling magnetic field. This will reduce the time spent on the preparation of the melt without losing the quality of the grown crystal. The research is carried out by two stage Two-dimensional numerical simulation of electromagnetic, hydrodynamic and heat exchange processes occurring during electromagnetic stirring of silicon was performed on the first one. In the second stage optimization of stirrer design was performed, as the objective function time of melt volume temperature alignment is selected. Numerical modeling was carried out in the COMSOL Multiphysics, optimization was performed in the MATLAB. The possibility of using electromagnetic stirring for the intensification of the process of temperature equalization is demonstrated. A variant of optimizing the design of electromagnetic stirrer is suggested, which allows to reduce the mass of the magnetic circuit by 30%.

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THE INITIAL MAGNETIC SUSCEPTIBILITY OF POLYDISPERSE FERROFLUIDS: NEW UNIVERSAL APPROACH

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Ferrofluids consists of ferromagnetic or ferrimagnetic nanoparticles suspended in a magnetically passive carrier liquid. The granulometric composition is rarely uniform within a given sample of ferrofluid, and therefore one needs to consider particle-size polydispersity. An effective way to determine the particle-size distribution within a sample is to analyze theoretically the magnetic properties, such as the magnetization curve and the initial susceptibility. The magnetization is usually described by the Langevin form with some effective magnetic field as inner parameter [1-4]. The choice of a certain set of terms in the structure of the effective field corrects the height and slope of the magnetization curve and some of the terms result in magnetic susceptibility. On the other hand, the initial magnetic susceptibility can be presented in the virial expansion form over powers of density. However, virial constructions are very sensitive to the number of terms which are taken into account in the series. The restriction of the set of terms can lead to both quantitative and qualitative change in the behavior of the susceptibility curve. In a recent work [4] two virial-type susceptibility theory [3] and [5] have been tested rigorously against results from Monte Carlo simulations of model monodisperse, bidisperse, highly polydisperse ferrofluids. These theories differ from each other only by a set of terms in the virial expansion of the susceptibility. Thus, the theory [3] contains three terms depending only on Langevin susceptibility, hence this approach predicts the same susceptibility values for systems with different particle size distribution and the same values of Langevin susceptibility. Theory [5] additionally takes into account three terms that depend on the granulometric composition in a complex way, which allows one to exactly describe the polydispersity of the system. It was shown [4] that theory [3] is most accurate for the monodisperse model, while the new theory [5] works best for polydisperse systems with a significant proportion of large particles. Therefore, the determination of a universal formula predicting a ferrofluid susceptibility for any type polidispersity of system remains as a challenge. In this work new approach has been developed for calculating of the initial magnetic susceptibility in an alternative form. The method uses the Helmholtz free energy, which is re-summed in to a logarithmic function. The analytical expression of the Helmholtz free energy allows to describe any properties of ferrofluids including the initial magnetic susceptibility. As a result, a new expression for the initial susceptibility was obtained in the form of a fraction, whose expansion in a Maclaurin series over powers of density exactly coincides with the theory [5]. Its success is due to the approximate representation of high-order terms in the virial expansion, while retaining the exact low-concentration behavior. It turns out that behavior of the new theoretical susceptibility formula is very close to the theory [3] for monodisperse systems and polydisperse systems with a narrow distribution of the particle diameters. In the case of polydisperse systems with a wide particle size distribution, the new theory approximates the theory [5] good enough. Therefore the new form of susceptibility is able to describe the Monte Carlo simulations data [4] relative to all model systems with any granulometric composition.

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HYDRODYNAMICS AND HEAT TRANSFER IN PIN BUNDLES WITH SODIUM COOLANT

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In SSC RF IPPE the complex of experimental thermohydraulic facilities with liquid metals is built, the methods of simulation, sensors, technique of experiments and engineering measurements are designed, the computational methods and codes are advanced. Thermohydraulic investigations have complex experimental and computational nature. The wide experimental data on velocity and temperature profiles, hydrodynamic resistance and heat transfer, initial thermal site in channels of the composite form and pin subassemblies, interchannel mixing of coolant are obtained. With their usage are advanced both engineering techniques of thermohydraulic calculation of pin bundles, and computational codes in an approaching of subchannel model of calculation and model of «porous medium». By experimentally and computationally way the features of hydrodynamics and heat transfer in intermediate heat exchangers and steam generators are investigated. It has allowed to carry out the substantiation of thermohydraulic characteristics of pin bundles.

CRITICAL AND ORDINARY HYDRODYNAMIC AND MAGNETISM OF PLANETARY INTERIORS

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Own magnetic field of a planet protects atmosphere against star wind making possible for any live to exist. The value, structure and evolution of the planetary magnetic field are linked to the properties of the planetary interiors those are also important for habitual planet. Correspondent critical and ordinary hydrodynamic and magnetic events are examined using the available knowledge about the Solar system planets. The first critical event is convection onset that is well-described numerically, asymptotically and even analytically for the typical planetary conditions. For the ordinary convection, I present new results related to the optimal similarity factors allowing the solution of the convection problem with real planetary parameters. The next critical event is magnetic field onset via convection that is determined by the properties and evolution of the planetary interiors. Ones established the ordinary magnetic field is mainly determined by the planetary heat/composition power flows and rotation. Here previously two-decade promising numerical planetary MHD dynamo-like first principal modeling has troubles nowadays in its' parameter space. It is been very far from realistic also gives doubtful access to the true physical scales and values via the known scaling laws. I have analytically reintroduced/supplemented those laws and suggested hopefully correct and new ones.

GEODYNAMO ESTIMATIONS BASED ON ORIGIN, EVOLUTION AND PROBABILISTIC TIME ANALYSIS OF GAUSS MULTIPOLES

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We express logarithmic time derivatives of geomagnetic multipoles via the fluid velocity and magnetic field in the Earth's core. Those derivatives or exponential rates are estimated by averaged product of velocity gradient with sinus of the angle between velocity and magnetic field vectors. The typical or averaged rates are related to the geodynamo power flow and to other not-well known dynamo parameters allowing their observational estimations. Basing on IGRF and gufm1 models we present four-century evolutions of the rates. It shows no harmonic periodicities with longer flat 'quiet' and shorter pick-shaped 'disturbed' fields. Rates related to axissymetric harmonics are typically two orders of magnitude smaller than the corresponding tesseral rates. The exclusion is axisymmetric quadrupole with extremely large rate 4/yr at 1650. This and similar picks ensure strongly non-linear geodynamo behavior. Developing our probabilistic time analysis we identify geomagnetic probabilities to grow/decay, expected values for grow/decay and median rates together with periodicity/aperiodicity estimates. The totals grow/decay variations defined as inverse rates are 25 yrs and median variations are 400 yrs since 1900. The typical disturbed fields' grow/decay variations 10 yrs followed by abrupt (1950-1960) or stepwise (1985-2000) return to quiet field. During quiet and moderately disturbed intervals the field is slightly dominated with periodical (or more precisely – half-periodical) behavior. While it jumps from almost absolute periodicity to sufficient aperiodicity during the strongest disturbances with variation 7 yrs in 1950-1960. From 1900 till 1995 the total probability for the geomagnetic field to grow was higher then to decay, while it preferably decayed since 2000.

A TIDALLY SYNCHRONIZED TAYLER-SPRUIT TYPE MODEL OF THE SOLAR DYNAMO

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We present a solar dynamo model of the Tayler-Spruit type whose Omega-effect is produced, as usual, by differential rotation but whose alpha-effect is assumed as being periodically modulated by planetary tidal forcing. This resonance-like effect has its rationale in the tendency of the current-driven Tayler instability to undergo intrinsic helicity oscillations which can be synchronized by periodic tidal perturbations. Specifically, we focus on the 11.07 years periodicity of the alignment of the tidally dominant planets Venus, Earth, and Jupiter. In the framework of a simple one-dimensional numerical model we prove the subcritical character of this Tayler-Spruit type dynamo. The typical dynamo modes are dipole fields, oscillating with a 22.14 year period, but also quadrupole fields pulsating with an 11.07 years period. Transitions between these field topologies are reminiscent of the observed behavior during the Maunder minimum. Further interesting features of the model are the emergence of mid-term fluctuations, and the intermittent appearance of reversed helicities in both hemispheres. With minor model modifications, the correct direction of the butterfly diagram comes out as a robust feature, too.

SELF-ASSEMBLY OF COLLOIDAL PARTICLES WITH A MAGNETIC COATING

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Recently designed soft functional materials open up perspectives for technical applications, from sensors to actuators and printed electronics. In this contribution we investigate magnetic Janus particles with a ferromagnetic coating on one hemisphere. They are characterised by an extended magnetisation distribution, with the local magnetization pointing perpendicular to the particle surface. We study the influence of low-frequency external magnetic fields on the self-assembly of these colloidal particles. In experiments, the formation of branched clusters of staggered chains, compact clusters, linear chains, and dispersed single particles can be selected. The experimental findings are complemented by molecular dynamics simulations, performed with a system of model colloidal particles that represent the extended magnetisation distribution as an off-centred, radially symmetric arrangement of five point dipoles. The results demonstrate that the diversity of controllable structures formed under external fields can be increased by means of two ingredients: the magnetic particle anisotropy and the spatial extension of the magnetization distribution on the surface of the particles. The precise control of structure formation and reconfiguration under external fields of only a few mT exhibited by this system opens up the possibility to use it in responsive materials for highly sensitive magnetic and optical applications.

CONDUCTIVE ELECTROMAGNETIC PUMP WITH PARTITIONS LOCATED PERPENDICULAR TO THE FLOW IN THE CHANNEL

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The main advantage of the pump presented in this work is the possibility of controlling the flow rate of liquid metal without changing the intensity of electric current in the channel. Usually, this requires changing of the winding current (for example, as in travelling field MHD-pumps). Sometimes it is necessary that a value of the electric current in the channel is kept fixed while the flow rate of metal is varied. The best and most reliable solution in this case is the mechanical movement of cores, which allows controlling the degree of overlapping the channel. Another advantage of the pumps of this type is the absence of windings, which makes it possible to operate them at high temperatures.

The flow in the pump channel is generated by an electromagnetic force by means of a conduction mechanism: the electric current is supplied to the input and output of the channel from an external source. The flat channel of the pump is made of a stainless steel with the partitions placed inside. They are arranged in a staggered order and partially overlap the channel. The openings between the partitions and the narrow walls of the channel serve to remove air when the channel is filled with metal or emptied after the end of the pumping process. The channel is surrounded by the U-shaped ferromagnetic cores. The current generates its own magnetic field, which penetrates the cores and magnetizes them. The magnetic induction is concentrated in the gap, its vector will be orthogonal to the current density vector. The resulting electromagnetic force generates a flow through the channel, which is of transient nature due to the presence of partitions.

The pump was tested on the gallium loop developed and assembled in the test laboratory of the ICMM UrB RAS. The loop equipment allows changing the hydraulic resistance of the loop and making measurements of the differential pressure created by the pump, the flow rate of the gallium alloy and the electric current flowing through the channel. After filling the channel with the alloy an alternating electric current was passed through it. In the experiment, the pressure drop in the stopping mode and the pressure drop at varying flow rates for different degrees of channel overlapping by the cores and their different numbers were measured. As a result of the analysis, the pressure-flow rate characteristics of the pump were determined for different degrees of the cores overlapping.

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WAVELET ANALYSIS OF MAGNETIC ENERGY AND CURRENT HELICITY IN THE SOLAR PHOTOSPHERE USING VECTOR MAGNETOGRAPHIC OBSERVATIONS

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We use advances of wavelet transform for scale analysis of magnetic energy and current helicity in the solar photosphere by using vector magnetographic observations of sunspots and solar active regions. We show spatial distributions of magnetic energy and current helicity at different scales. Inhomogeneity and local anisotropy are discussed. Magnetic helicity plays an important role in magneto-hydrodynamics of plasmas. For solar dynamo, it is a crucial constrain on the mechanism of cyclic regeneration of magnetic fields, so it is very important for understanding the underlying physics of the solar dynamo. We reveal the scales at which various properties of spatial helicity distribution contribute to its overall integral. The latter is inviscid invariant in ideal MHD.

MAGNETIC ENERGY AND HELICITY MODE-TO-MODE TRANSFERS IN A DYNAMO ACTION

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It is generally believed that helicity can play a significant role in turbulent systems, e.g. supporting the generation of large-scale magnetic fields, but its exact contribution is not clearly understood. There are well-known examples of large scale dynamos produced by a flows which are pointwise non-helical (Roberts, 1972). Recently the low dimensional model is suggested (Stepanov & Plunian, 2018) which is likely able to capture a common particularity of the dynamo mechanism produced by simplest flows. This model based on two Fourier modes for the flow and three Fourier modes for the magnetic field. The dynamo acts within the tetrahedron formed by these modes. The analytical results were shown for diffusionless limit.

The present work deals with the kinematic dynamo produced by type I and type II Roberts flows, solving the diffusive induction equation for all Fourier modes. We show that dynamo mechanism takes a place indeed within simplistic tetrahedron model. Our analysis based on the kinetic and magnetic energy fluxes and mode-to-mode transfers as well. We emphasis a role of magnetic helicity which is redistributed among Fourier modes following conservation law. The total value of magnetic helicity grows due to magnetic diffusion. We explain oscillatory character of the dynamo by type II flow.

MACROSCPIC MODEL OF STRUCTURE FORMATION IN MAGNETORHEOLOGICAL ELASTOMERS

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Magnetorheological elastomers (MREs) are smart composites obtained by embedding magnetic micron-size iron particles in weakly-linked rubber-like matrices. These materials are sufficiently soft rheologically and sufficiently loaded magnetically as to display considerable magnetomechanical effects like large field-induced strains, notable field-tuning of the effective elastic modulus, a specific type of shape-memory behavior and some other unique properties.

An important intrinsic feature of MREs is the field-induced particle aggregation. Since the interparticle magnetic forces are anisotropic, they tend to structure a MRE in a certain way, namely: to arrange the particles in chains directed along the field. Under this influence, the particles, initially distributed by large randomly, strive to shift from their original positions. This tendency is opposed, however, by the elastic forces generated by the polymer network, and those forces are the greater, the more significant the particle displacements. Given the magnitude and direction of the applied field, each MRE particle moves until it comes to a position that corresponds to local balance of the magnetic and elastic forces. Evidently, the observed (macroscopic) magnetomechanical response of a MRE is the sum of all those intrinsic changes which take place at the mesoscopic level.

In this work we propose a model to describe the behavior of a MRE in the regime of sufficiently strong external field. Summing up in simple terms the results accumulated in numerical modeling (explicit evidence) and experiment (implicit evidence), we infer that at a certain stage of magnetization the isolated clusters unite in global ones, i.e., the aggregates which traverse the whole sample, thus building a structure «skeleton». On that occurrence, a strong change in the properties of the material takes place; in particular, the modulus of elasticity increases by several orders of magnitude. To account for that structure change, we extend the set of thermodynamic parameters, which characterize the macroscopic state of a MRE. Along with the standard pair — magnetic field $\mathbf{H}$ and stress tensor $\boldsymbol{\sigma}$, — two new macroscopic quantities are taken in consideration. They are: φ (a scalar) that is the fraction of magnetic particles entering global clusters, and a traceless tensor $\mathbf{S}$, which accounts for the orientation of the structure. This step entails appearance of additional contributions to the energy density of MRE — proportional to $\varphi\mathbf{H}\cdot\mathbf{S}\cdot\mathbf{H}$ and to $\varphi\mathbf{S}\cdot\cdot\boldsymbol{\sigma}$ — which, respectively, render the field and stress effects on cluster orientation. Treating φ as the order parameter, we use a Landau-like theory [1] and interpret the global cluster formation as a second order phase transition occurring at critical field H_c.

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INFLUENCE OF VISCOSITY ON THE BEHAVIOR OF SUSPENSIONS CONTAINING MAGNETIC NANOPARTICLES IN ROTATING MAGNETIC FIELD

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In an external rotating magnetic field, the magnetization of magnetic nanoparticles follows the field direction with a certain phase lag, which results in a macroscopic torque. We investigated experimentally the dependence of the torque density on the strength and frequency of the magnetic field, as well as on the viscosity of suspensions containing magnetic nanoparticles. The torque density increases with the square of the field strength; this can be explained by well-known expressions. At the same time, the magnetization direction changes slower than the external magnetic field due to the relaxation of magnetic nanoparticles. The dependence of the torque on frequency is thus complex and depends on the viscosity of magnetic suspensions. We find a growth of the torque with rotation rate of the field, followed by a decay at higher rates. The torque maximum shifts with changing viscosity. This phenomenon can be related to the balance of Neel and Brownian relaxation times.

MATHEMATICAL MODELLING OF AN INVERSE FERROFLUID EMULSION: CASE OF NONLINEAR FERROFLUID MAGNETIZATION.

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An inverse ferroemulsion is a system of nonmagnetic fluid micro droplets (radius ≈ 5–10 μm), suspended in magnetic fluid carrier. Experimental study of the static magnetic properties of such systems [1, 2] has demonstrated the nonmonotonic field dependence of the emulsion magnetic permeability. In a weak magnetic field, the emulsion permeability grows and reaches a maximum, and then it decreases slowly in stronger fields. The growth is caused by the droplet elongation and the resulting reduction of demagnetizing field under the constant value of the ferrofluid magnetic susceptibility. This behavior is pronounced for emulsions with rather weak values of the interfacial tension ($\sim 10^{-6}$ N/m). Subsequent decrease of the emulsion magnetic permeability in a stronger magnetic field is explained by the decay [3] of the ferrofluid magnetic susceptibility under an approximately constant degree of droplet elongation. The one of the main parameters which influences on speed of the initial growth of magnetic permeability is a size distribution of the droplets. As it showing in our previous works for the direct ferrofluid emulsions the presence of large drops in the system tends to higher speed of magnetic permeability growth [4]. For the inverse ferroemulsions the same result is obtained only in case of linear magnetization low with constant value of ferroluid magnetic susceptibility. On the other hand the maximum value of the magnetic permeability of the emulsion is depends on decay [3] of the ferrofluid magnetic susceptibility under, where the ferroluid magnetic susceptibility is nonlinear depends on applied magnetic field strength. In this work the mathematical model of an inverse ferrofluid emulsion in the case of nonlinear law of ferrofluid magnetization is presented. In additional the influence of droplet polydispersity is taking into account.

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DYNAMICS OF A TURBULENT SWIRLING FLOW IN A TOROIDAL CHANNEL

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The main goal of presented study is temporal evolution of turbulent swirling flow in a toroidal channel. Earlier series of experiments gave as a result temporal dependencies of azimuthal component of swirling flow at the entry and exit of the divertor [1,2]. It was also shown that described in [1,2] configuration allows to produce developed swirling flow which occupies the whole channel. Measurement in [1,2] were carried out for tori of different radii of torus and channel but for similar aspect ratio ($a = 0.26$). Recent studies of MHD-flows in a toroidal channel showed that the value of aspect ratio may be of crucial importance and can substantially influence on the structure and evolution of the flow. Measurements in a liquid sodium in a rotating toroidal channel is a serious problem because liquid sodium is a non-transparent and aggressive fluid. The kinematic characteristics of the water are very close to the ones of the liquid sodium, so water experiments in tori of different aspect ratios can provide valuable information about the structure of the flow. Measurements were carried out for two different aspect ratios by high-speed video camera. Temporal dependencies of longitudinal velocity were obtained and analyzed.

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NUMERICAL SIMULATIONS OF LIQUID MAGNESIUM AND MAGNESIUM SALT CONVECTION IN THE TITANIUM REDUCTION REACTOR

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In this work we introduce a hydrodynamic model of convective flows in a titanium reduction reactor. The reactor retort is a cylindrical vessel with a radius of 0.75 m and a height up to 4 m, filled with liquid magnesium at a temperature of 850°C. The exothermic chemical reaction on the metal surface, cooling of the side wall and heating of the lower part of the retort cause strong temperature gradients in the reactor during the process. These temperature gradients cause intensive convective flows inside the reactor. As a result of the reaction, a block of titanium sponge grows at the retort bottom and the magnesium salt, whose density is close to the density of magnesium, settles down. Control of the reaction during this complex physical-chemical process is one of the essential problems of metallurgical production. Large mass and dimensions of the apparatus as well as very high temperatures complicate the direct experimental measurements inside the reactor, which is one of the motivations for our numerical study of the process. Up to present all models considered only the convective flow of liquid magnesium, with and without presence of titanium sponge, and ignored the contribution of the second liquid phase — magnesium chloride. In the present paper we consider the flow of a two-phase system of immiscible fluids (liquid magnesium and magnesium salt) and analyze the settling of salt in the presence of strong convective flow inside the reactor. The process of magnesium salt settling in a titanium reduction reactor was numerically studied in a two-dimensional and three-dimensional non-stationary formulation, which allowed us to construct the instantaneous and average characteristics of the process and to analyze the velocity and temperature pulsation fields. The numerical code solves the equations for two-phase fluid (liquid magnesium and magnesium salt). All the simulations were run using the free and open source finite volume code OpenFOAM 4.1. OpenFOAM includes the solver multiphaseInterFoam which relies on the Volume of Fluid (VOF) method and intends to solve problems with incompressible fluids, capturing the interfaces and including surface-tension and contact-angle effects for each phase, while not taking into account buoyancy effects. This solver is enhanced by the temperature equation using the Boussinesq approximation. The numerical simulations were performed using the supercomputer Triton of ICMM UB RAS. The two-dimensional mesh has 0.95 million grid points, while three-dimensional mesh has 3.5 million nodes. A detailed analysis was performed for configurations with and without presence of convective flow due to work of furnace heaters. Fundamental differences in convective flow structure for these heating regimes have been revealed. It has been established that magnesium salt is settling in drops with sizes from ~ 3 cm to ~ 10 cm. The velocity of drops (~ 18 cm/s to ~ 30 cm/s, depending on regime) is higher than the velocity of the convective flow (up to 20 cm/s), but it was shown that convective flow can entrain the drop and carry it with the vortex.

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INVESTIGATION OF THE ROSSBY VORTICES IN THE ELECTROVORTEX FLOW IN HEMISPHERICAL GEOMETRY

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Among the different types of magnethydrodynamic flows with liquid-metal heat-transfer medium, the so-called electrovortex flows (EVF) formed as a result of the interaction between the electric current passing through the electroconductive liquid and the electric current own magnetic field are of special interest for investigators [1]. Investigation of the electrovortex flows has not only fundamental orientation but also is of great importance for different branches of machine-building, energetics and metallurgy [2]. For example, EVF affects the quality of the weld at submerged arc welding and the presence of EVF changes the evolution dynamics of electroslag remelting. External axial magnetic field in this geometry leads to the azimuthal swirl of the flow. And rotating flow can create vortices on the surface similar to Rossby vortices [3]. Experiments on measurements of the azimuthal velocity were carried out at the following setup. An eutectic indium-gallium-tin alloy (weight content: Ga-67%, In-20.5%, Sn-12.5%, physical properties: melting point +10.5°C , density = 6482 kg/m^3, viscosity = $4.3 \cdot 10^{-7}$ m^2/s, conductivity = $3.3 \cdot 10^6$ Sm) was used as the working liquid in the experiments. Alloy filled a copper hemispherical container with the radius R2=94 mm which also served as a large electrode. Small electrode — copper or steel cylinder with the radius R1=2.5 mm with hemispherical tip was immersed into the alloy in the middle of the working bath. Power source developed on the basis of three-phase AC rectifier ($I \leq 1500$ A) was used to supply an experimental setup. To create an external longitudinal magnetic field up to 0.1 T the coil consisting of ∼300 turns was used. A hydrochloric acid solution was used to visualize the flow on the surface. Numerically, the simulation was based on the solution of the Navier-Strokes equation with an added electromagnetic force causing the toroidal and azimuthal motion of the fluid. To solve Navier-Stokes equation we used the finite volume method on an unstructured 3D grid in cylindrical coordinates. Unsteady calculations of the velocity were carried out for different ratios of the small and big electrode. The results of experiments and calculations showed that under an external magnetic field of more than 0.02 T on the surface of a liquid metal, under our conditions, structures similar to Rossby vortices can form. Also, the parameters at which this effect was realized were determined.

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HELICAL EFFECTS IN FORCED MHD TURBULENCE

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Magnetohydrodynamic (MHD) turbulence is an intrinsic part of astrophysical phenomena, which plays a crucial role is the generation of cosmic magnetic fields. The two-scale dynamo concept suggests that the small scale interactions are demanded to drive the large scale magnetic fields of planets, stars and galaxies. Since experimental study of MHD turbulence is almost impossible the numerical simulation is only a way to verify theoretical ideas and phenomenology. We studied different types of forcing functions and their influence on MHD turbulence. Our attention was focused on energy and helicity transfer and non-local shell-to-shell interactions. It is shown that decomposition of total energy flux into components allows to identify energy transfer mechanism. Significant influence of non-local interactions in strongly helical cases is presented.

THE CHARGE DISTRIBUTION IN A FLAT CAPACITOR IN THE PRESENCE OF THE DIFFUSION AND ANONYMOUS UNIPOLAR INJECTION

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The aim of this investigation is to describe the charge distributions and the dynamics of the currents inside a quiescent uniformly heated low conducting liquid filled a flat horizontal capacitor under the action of a constant electric field and an autonomous injection from one of the electrodes. It is assumed that charges propagate due to their mobility in the electric field and diffusion current. Within the framework of this work, a one-dimensional mathematical model is used in which changes of all physical quantities occur along the coordinate axis perpendicular to the surfaces of the electrodes. The boundary conditions for the charge at the cathode are considered of two types: 1) the diffusion current at the boundary is zero; 2) the diffusion current is fixed and different from zero. The charge density at the anode is determined of the injection coefficient (level). In the initial state the charge is absent in the capacitor. For arbitrary values of the autonomous injection coefficient the solution is obtained numerically using the method of finite differences. In the case of weak injection the solution is found analytically with the help of expansion in series of a small parameter). Charge distributions in the capacitor are obtained for different moment of time. The time evolutions of 1) value of the total charge in the capacitor and 2) the current at the cathode are analyzed for different values of diffusion coefficients and injection level. Analysis of the results allows us to made the following conclusions: 1) The time of the evolution of charge distribution from initial to final steady state decreases with increasing diffusion and injection coefficients. 2) If the injection coefficient is less than 0.1, the numerical and analytical solutions agree well. The difference between them increases with a further increase in the intensity of injection.

NUMERICAL INVESTIGATION OF MHD HEAT TRANSFER IN A LIQUID METAL UPWARD DUCT FLOW WITH A COPLANAR MAGNETIC FIELD

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The heat transfer processes occurring during the motion of molten metal in a tokamak are complicated by magnetohydrodynamic and free convection effects. Their manifestation is due to the presence of strong magnetic fields and high thermal loads. The features of liquid-metal heat exchange have been studied for many years by the joint scientific group of the Moscow Power Engineering Institute (MPEI) and the Joint Institute of High Temperature (JIHT) of the Russian Academy. In particular, a series of experiments was done at the laboratory bench, aimed at a detailed study of heat transfer in forced convection of mercury in a vertical heated channel in a coplanar magnetic field [3]. The present work is devoted to the Direct numerical simulation (DNS) of MHD heat transfer in the elevated flow of liquid metal in a channel of rectangular cross section under heating conditions [1]. This approach is based on the complete Navier-Stokes equations without the use of approximations and averaging. Thus all the space-time scales of turbulence are resolved. The finite difference method is used for the solution of partial differential equations. Spatial sampling has a second order of accuracy. Integration over time is carried out using the semi-implicit Adams-Bashforth scheme. A numerical experiment was performed with different ratios of the regime parameters Re, Gr, Ha. After the completion of the series of calculations, the grid convergence analysis was performed. A number of characteristic features are manifested in the fluid flow under the influence of thermogravitational convection and an applied magnetic field based in the results of this work by using the method DNS [2]. The results of the CFD calculation were compared with the available experimental data [3]. In addition, the DNS allowed to get fields of turbulent characteristics, the consideration of which is difficult or even impossible in the conditions of full-scale experiment.

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MODEL OF A MAGNETIC ELASTOMER WITH EMBEDDED MULTIGRAIN MAGNETIC PARTICLES

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Magnetorheological elastomers (MRE) are composite materials consisting of magnetic particles embedded into a soft polymer matrix. The mechanical properties of the MRE can be tuned by applying a magnetic field that will interact with the magnetic particles inside a sample. In order to estimate those effects qualitatively and quantitatively one needs to investigate magnetization process of an MRE sample. When the concentration of the magnetic phase is low, the dipole-dipole interaction between particles can be neglected. In that case, in order to simulate the magnetization curves of a whole sample it is necessary to model magnetization processes of separate particles. If a particle is large enough to be multidomain, we need to consider structuring of domains during its magnetization. In our investigation we aim at the experimentally available data [1] obtained on the MRE that contained commercially available MQP-S-11-20001 magnetic powder made of round magnetically hard particles with the mean linear size of 46.8 μm. The powder is produced during centrifugal or spinning cup atomization process. This technology produces particles consisting of metallurgical grains of about single-domain size [2]. It was discovered that in such materials the domain walls coincide with the grain borders and those walls do not move during magnetization of the compound particle. Considering the above mentioned, we model a magnetically hard microparticle as a structure of tightly packed single domain grains that do not move inside the particle but the particle itself can rotate with respect to the surrounding matrix of the elastomer. Magnetization of the grains is described by means of the Stoner-Wohlfarth model. Grains are modelled as point magnetic dipoles, which can interact with each other. Rotation of the microparticle makes the MRE magnetization process distinctive from the magnetization of hard materials, particularly, it reduces coercivity of the MRE samples and shifts their hysteresis loops into negative values of the field. The developed model allows one to model the magnetization curves of the MRE samples and to show the dependence of the curve shapes on different magnetic properties of particles and elasticity of the matrix. The dipole-dipole Interaction of the grains results in the fact that the magnetization saturation state is reached at relatively high field values, what was also observed during the experiment [1]. Using the model one can also calculate the first-order reversal curve diagrams of the MREs. Such diagrams represent the distribution of microparticles over their coercivity and position of their individual hysteresis loops with respect to the origin. The modelled diagrams might be further compared with those obtained from an experiment in order to estimate the quality of produced MRE samples.

The work was supported by the RFBR projects No. 17-42-590504 and No. 17-41-590160.

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ENERGY TRANSFERS IN MAGNETOHYDRODYNAMICS: PERSPECTIVES FROM DNS AND SHELL MODEL

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In this general talk, I will present the formalism of computing energy transfers maninly fluxes namely, kinetic to magnetic, and magnetic to magnetic. These transfers are useful for understanding dynamo mechanism. We will compare the results from DNS and shell models.

A STUDY OF THE APPLICABILITY OF THE ELECTRODYNAMIC APPROXIMATION IN THE SIMULATION OF THE ELECTROVORTEX FLOW WITH THE PRESENCE OF AN EXTERNAL MAGNETIC FIELD

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Electrovortex flow (EVF) is formed as a result of interaction between the non-uniform electric current passing through the liquid metal and the own magnetic field of this current [1]. Such flows significantly affect many processes in mechanical engineering (electro-welding) and electrometallurgy (electroslag remelting, various electric melting furnaces). In particular, electrovortex flow determines the hydrodynamic structure in the baths of DC-arc furnaces, which are increasingly used in the industry [2]. In hemispherical geometry, when an electric current is passed through the liquid metal from the central small electrode to the electrode-container, the EVF has the shape of a toroidal vortex. Also, EVF is very sensitive to the axial external magnetic field that creates an azimuthal force and leads the flow to rotation, while this rotation turns out to be quite intense due to the whirlpool effect caused by the main converging current. In numerical simulation, a term containing the electromagnetic force $F = j \times B$ is added to the Navier-Stokes equation, where J is the current density that includes the conduction current (sigma*E) and the current induced by the fluid motion (sigma*UxB), B is the magnetic field induction, electric field strength, sigma - conductivity. At currents up to 30 kA and the absence of external magnetic fields, one can use the so-called "Electrodynamic" approximation, when the term sigma*UxB can be neglected [3]. We investigated applicability of electrodynamic approximation with the influence of the external axial magnetic field (MF). We used finite volume method on an unstructured 2D-axisymmetric grid in cylindrical coordinates to solve Navier–Stokes equations numerically. Experiments on measurements of the azimuthal velocity were carried out at the following setup. An eutectic indium-gallium-tin alloy (weight content: Ga-67%, In-20.5%, Sn-12.5%, physical properties: melting point $+10.5^\circ\ C$, $\rho = 6482$ kg/m^3, $\nu = 4.3 \cdot 10^{-7}$ m^2/s, $\sigma = 3.3 \cdot 10^6$ Sm was used as the working liquid in the experiments. Alloy filled a copper hemispherical container with the radius $R2 = 94$ mm which also served as a large electrode. Small electrode — copper or steel cylinder with the radius $R1 = 2.5$ mm with hemispherical tip was immersed into the alloy in the middle of the working bath. Power source developed on the basis of three-phase AC rectifier (I$\leq$1500 A) was used to supply an experimental setup. To create an external longitudinal magnetic field the coil consisting of $\sim$300 turns was used. The results of the calculations showed that at external magnetic fields B$>$0.005T difference in azimuthal velocity with and without term UxB reaches more than 10%. At such and higher values, the magnetic field exerts a retarding effect on the azimuthal velocity and the azimuthal velocity begins to grow much slower with increasing magnetic field. Therefore electrodynamic approximation is not applicable at external axial magnetic fields B$>$0.005T.

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NEW REQUIREMENTS AND APPROACHES IN DEVELOPMENT OF ELECTROMAGNETIC PUMPS FOR LIQUID METAL FAST BREEDER REACTORS

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At present, projects of new generation fast breeder reactors (FBR) [1] including those with sodium coolants (BN-1200, MBIR) continue to be developed in Russian Federation. Technical solutions of such reactors are aimed above all to improve safety performance with compliance to applicable safety standards, including system of standards on atomic energy equipment (1st, 2nd and 3rd classes) and obligatory certification that has been put into operation since July 2017. Electromagnetic pumps (EMP) of main and auxiliary systems of those reactors need to provide the required long service life at high liquid metal temperatures that are, for example, 50 years at 300°C for EMP of MBIR second loop, and 15 years at 410°C for immersed EMP of BN-1200 cold trap. New methods and approaches in development of electromagnetic pumps for liquid metal fast breeder reactors are considered based on the design of immersed EMP of BN-1200 cold trap. Results of complex research of novel high temperature resistant electrical engineering materials to meet service life requirements at high temperature are shown. Main issues on improvement of manufacturing technology of those materials are stated. Computational results aimed to optimize EMP design, fulfill stated above requirements and confirm specified parameters are presented.

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SOME GENERALIZATIONS OF THE LORENTZ SYSTEM AS DYNAMO MODELS

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The one of the known applications of the classical Lorentz system is an axisymmetric AlfaOmega-dynamo with a dynamical quenching of the alpha effect by the helicity of the magnetic field. The dynamical component of the alpha-effect in this case can be considered as a functional of the helicity of a field with an exponential kernel. The report discusses the generalizations of this model in four parts: 1) use of other types of kernels, which allow simulating the lagging of quenching and the memory in the dynamo-system; 2) quenching of the alpha-effect by the energy of the field; 3) Alfa2Omega-dynamo modeling. Analytical and numerical studies of phase spaces, regimes of regular and chaotic inversions, dynamo bursts are described. Statistical distributions of polarity intervals are studied. The work was supported by a grant from the RSF 14-11-00194.

THERMODYNAMICS AND PHASE SEPARATION IN BIDISPERSE DIPOLAR HARD SPHERES

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The bidisperse system of dipolar hard spheres (DHSs) is used to study thermodynamics and phase separation of ferrofluids. Considering bidisperse DHSs, we assume existing of two ferroparticle fractions: small and large particles, which differ in their diameters and magnetic moments. Each fraction has its own characteristics: the number of particles, the volume concentration, and dipolar coupling constant.

The theory is based on the transformation of the virial expansion for the Helmholtz free energy into the logarithmic form [1]. In this work, the second and the third virial coefficients are calculated as a series expansion in the dipolar coupling constant up to the forth power in zero magnetic field and in the presence of magnetic field the second and third virial coefficients are calculated up to the second order. The new theory extends the thermodynamic results obtained for the monodisperse DHSs [1, 2] and bidisperse DHSs [3]. This theoretical model is applied to study phase separation in bidisperse ferrofluids. In this work we predict critical parameters of bidisperse system and the parameters of coexisting phases. The results for bidisperse system are compared with the ones for monodisperse model to study the influence of polydispersity on phase behavior of ferrofluids.

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MHD OF LIQUID METAL BATTERIES

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Liquid metal batteries (LMBs), developed originally during the 1960s in the United States, experienced a renaissance some ten years ago at MIT. Built as stable density stratification of two liquid metals, which are separated by a molten salt, they offer potentially very cheap stationary energy storage. Thus, LMBs may be the key enabler for a large scale deployment of highly fluctuating renewable energy sources. Especially their potentially long life time, the extremely high current densities and the cheap active materials make the cells an ideal candidate for stationary energy storage. Fluid flows will naturally appear in the fully liquid cells. On the one hand, convection can be beneficial when enhancing mass transfer and improving the cell efficiency. On the other hand, strong flow must be avoided to ensure a safe operation. The talk will give an introduction to the set-up and working principle of LMBs. The second part will be devoted to fluid dynamic instabilities in the cells; both numerical and experimental results will be presented. The talk will focus on long wave MHD interface instabilities (as known from aluminium reduction cells), on thermal convection, and electro-vortex flow.

NUMERICAL MODELING OF DYNAMICS IN VORTEX LATTICES FOR PLANE MHD FLOWS

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Spatially periodic flow patterns, in particular, vortex lattices, often serve in fluid mechanics as basic elements in experimental, theoretical and numerical studies of spectral and transport properties of velocity fields [1-4]. Geometry of these patterns usually owes to application of spatially periodic forcing. In the experiments on formation and decay of large-scale turbulent structures [5,6], spatial periodicity of the underlying plane flow has been ensured by positioning arrays of electrodes and/or permanent magnets at the bottom of thin layers of electrically conducting fluids. Theoretical studies of hydrodynamical instabilities in this class of models can be traced back to the Kolmogorov flow and its generalizations [1,7]; stability borders of the basic one– and two-dimensional flows have been determined, and transition to oscillatory patterns has been predicted [7]. Here, we numerically investigate the three-parameter family of forced plane doubly periodic flows (flow on a torus) [8]. The dimensionless parameters of the problem are the flow rates in two perpendicular directions Re_1 and Re_2, respectively, and the intensity of the forcing. When the forcing amplitude is increased, the exact solution of the Navier-Stokes equations for this setup displays the structural rearrangements [3]: isolated vortices appear on the background of the global flow. In the case of the irrational "mean inclination" of the flow Re_1/Re_2, this leads to presence of the fractal component in the Fourier spectra of Lagrangian observables (e.g. velocity of passive tracers carried by the flow), as well as to subdiffusive transport. We investigate the stability of the exact solution in the parameter space, compute the bifurcation diagrams and numerically simulate the secondary oscillatory flows that exist outside the stability region. As a generalization of this family of flows, we suggest the three-dimensional version in which the additional (vertical) component of the velocity field stays independent of the vertical coordinate. This configuration is interesting from the viewpoint of the possible presence of the kinematic α-effect, which, in turn, can lead to the possibility of the kinematic dynamo action [2].

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BEHAVIOR OF THE CURRENT-CARRYING MELT EXPOSED TO THE ACTION OF EXTERNAL VERTICAL MAGNETIC FIELD IN A DIRECT CURRENT ARC FURNACE BATH

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Electrometallurgy deals with high temperature melts (metal, slag) and the behavior of these melts depends to a great extent on phenomena caused by the interaction of the electric current going through the melt with its own magnetic field and external magnetic fields. When the external vertical magnetic field acts upon the current-carrying melt in the liquid bath of the arc furnace, volume electromagnetic forces arise causing movement of the melt. However, the intensity and the pattern of the liquid flow can have both positive and negative influence on the production processes taking place in the bath. For example, one of the ways to intensify and control the process of heat-and-mass transfer in the bath is to provide its conductive stirring. Practical application of this technology is restricted by both lack of theoretical investigation of the influence of external magnetic field on the processes taking place in the liquid bath of the arc furnace in the process of metal and alloy production and by practical reasons, such as the lack of reliable sources of external magnetic fields. Investigation of behavior of metallurgical melts with both their own magnetic field and the external one at operating metallurgical facilities is impractical for many reasons, that is why, the investigations using mathematical and physical modeling are still urgent. The article offers theoretical justification of the investigation of the behavior of metallurgical current-carrying melt flow under the influence of external magnetic fields making use of physical models using non-metallic electrically conductive transparent liquids. The research group carried out physical modeling of the influence of external vertical magnetic field on the pattern of the current-carrying liquid flow in the bath for different switching options of bottom electrodes to the current power supply including the option of switching current of different frequencies. A 5-ton bath of a steel-making direct current furnace was used in the process of modeling. Sodium chloride-water solution was used as a model liquid. This made it possible to use video shooting to assess the speed of the liquid on the free surface and in the vicinity of the bottom electrodes. The research group used visual observations to find out the pattern of liquid flow in the bath when the central and two off-axis bottom electrodes were switched on. Assessments of azimuth velocities of flows were obtained on the surface of the liquid along the bath radius and in the vicinity of the bottom electrodes for different values of current going through them. The experiments made it possible to come to the conclusion that the pattern of the flow depends on the strength of the external vertical magnetic field and its direction; on the strength of current going through the electrode modeling the arc spot; on the number of bottom electrodes, on the connection pattern and the switch frequency of the current going through them. Mathematical modeling was used to obtain the distribution of volume electromagnetic forces in the model bath and their behavior in the real bath of an arc furnace under the influence of external vertical magnetic fields caused by the currents going through the buses of current leads of different layouts. As a result of the analysis the authors showed that it is possible to transfer the results of modeling to the processes taking place in the melt bath of a 5-ton industrial steel-making direct current arc furnace.

NEW EXACT SOLUTIONS OF MHD EQUATIONS FOR THE FLOW BETWEEN TWO INFINITE DISCS. SPONTANEOUS ROTATION

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We consider the MHD flow of viscous electroconductivc noncompressible liquid between two fixed impenetrable disks. Disks can rotate with constant angular velocity around the common axis. On each disk one can set the normal component of velocity (If the discs permeable) and normal component of homogeneous density of electric current (electric drive case). The exact solution of the complete system of MHD equations, belonging to the Karman class flow when the axial velocity depends only on the axial coordinate is investigated. The magnetic field has a similar form. Boundary conditions are: non-slip conditions for velocity, continuity of normal components of electric current density and magnetic field. Special attention is paid to the flow problem with fixed impenetrable disks. On the upper disk the normal component of vector of homogeneous electric current density is set. The lower disk is nonconducting. The problem has two non-dimensional parameters - the value of electric current density on upper plate Y and Batchelor number Bt (magnetic Prandtl nurnber). In the problern there is no external source of magnetic field. Axial magnetic field is absent. The range of Batchelor number between 0 and 2 is studied. For small values of Y the MHD flow is induced by the electric current and represents the flow from upper disk to bottom disk. With the growth of Y the intensity of flow is enhanced and at critical value of Y the bifurcation of rotational flow regime occurs. The new solution with rotation of fluid is stable. The previous solution without rotation becomes unstable. It is interesting that due to this bifurcation no axial magnetic field is generated as it usually occurs in MHD dynamo. Thus, the new type of bifurcation of rotation in MHD flow was observed. This phenornenon takes place in the exact solution of cornplete MHD equations, therefore the physical mechanism of this bifurcation should be presented in real flows and can be observed in experiment.

MULTI-SCALE ANALYSIS OF TURBULENT TRANSPORT IN STRONGLY COMPRESSIVE MAGNETOHYDRODYNAMIC FLOW

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In strongly compressible turbulence, where the fluctuation dilatation $\nabla \cdot \mathbf{u}'$ is large ($\mathbf{u}'$: velocity fluctuation), the effects of density fluctuation represented by the density variance $\langle \rho'^2 \rangle$ as well as the mean density stratification $\nabla \overline{\rho}$ should be properly taken into account. Turbulence correlations in compressible magnetohydrodynamics (MHD) are explored with the aid of a multiple-scale analysis coupled with a renormalized perturbation theory of turbulence. By introducing slow and fast variables with scale parameter expansions, the fundamental equations are analytically investigated in a perturbative manner. According to the theoretical analysis, the turbulent electromotive force (EMF), for instance, is expressed as

$$\begin{aligned}\langle \mathbf{u}' \times \mathbf{b}' \rangle &= -(\beta + \zeta) \nabla \times \mathbf{B} + \alpha \mathbf{B} - (\nabla \zeta) \times \mathbf{B} + \gamma \nabla \times \mathbf{U} \\ &\quad - \chi_{\overline{\rho}} \nabla \overline{\rho} \times \mathbf{B} - \chi_Q \nabla Q \times \mathbf{B} - \chi_D \frac{D\mathbf{U}}{Dt} \times \mathbf{B} \end{aligned} \tag{1}$$

($\mathbf{b}'$: magnetic-field fluctuation, $\mathbf{B}$: mean magnetic field, $\mathbf{U}$: mean velocity, Q: mean internal energy). Here, β, ζ, α, γ, $\chi_{\overline{\rho}}$, χ_Q, and χ_D are the transport coefficients expressed in terms of the spectral and response functions of the turbulence in the present framework. In addition to the usual dynamo terms (from the first to the fourth terms) [1], we have new χ-related terms intrinsically arising from the density variance [2]. For instance, the transport coefficient for the mean-density stratification, $\chi_{\overline{\rho}}$, is expressed as

$$\begin{aligned}\chi_{\overline{\rho}} &= \frac{1}{3} (\gamma_s - 1)^2 \frac{Q}{\overline{\rho}} \int d\mathbf{k}\, k^2 \int_{-\infty}^{\tau} d\tau_1 \int_{-\infty}^{\tau_1} d\tau_2 \int_{-\infty}^{\tau_2} d\tau_3 \\ &\quad \times \left[G_{u\mathrm{S}}(k;\tau,\tau_1) + G_{u\mathrm{C}}(k;\tau,\tau_1) \right] G_q(k;\tau,\tau_2) G_b(k;\tau,\tau_3) Q_{u\mathrm{C}}(k;\tau_2,\tau_3), \end{aligned} \tag{2}$$

where γ_s is the ratio of the specific heats for constant pressure to constant volume, $G_{u\mathrm{S}}$, $G_{u\mathrm{C}}$, etc. are the Green's functions of turbulence (the index C denotes the compressible parts while S denotes the solenoidal ones), and $Q_{u\mathrm{C}}$ is the spectral function of the compressible turbulent energy. Following this analytical result, can be modeled as

$$\chi_{\overline{\rho}} = (\gamma_{\mathrm{s}} - 1)^2 \frac{\tau_u \tau_q \tau_b}{\tau_\rho^2} \frac{Q}{\overline{\rho}} \frac{\langle \rho'^2 \rangle}{\overline{\rho}^2}, \tag{3}$$

where τ_u, τ_q, etc. are the timescales of turbulence linked with the Green's functions. A similar analysis was done for several important turbulence correlations such as the turbulent mass flux, Reynolds and Maxwell stresses, turbulent heat flux, etc.

Physical pictures of those effects arising from strong compressibility are discussed, including the role of density variance in turbulent dynamo and that of compressional Alfven wave in turbulent mass and heat fluxes along the mean magnetic field.

The $\chi_{\overline{\rho}}$-related term in Eq. (1) indicates that, in the presence of the density variance, an obliqueness between the mean density gradient and the mean magnetic field may contribute to the electromotive force. A possible application of these density-variance dynamo effects on the turbulent magnetic reconnection will be also presented.

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LARGE-SCALE AND SMALL-SCALE PROCESSES IN KAZANTSEV DYNAMO MODEL

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The most popular small-scale dynamo model was suggested by Kazantsev in 1967 for self-generation of random magnetic field frozen in a turbulent flow of conductive fluid. In spite of specific additional conditions, such as an isotropy of velocity field delta-correlated in time in unbounded area, this model allows one to describe the general features of dynamo process at the scales much smaller than typical correlation length of velocity field. Moreover, in the frame of this model there were obtained the estimates of critical magnetic Reynolds numbers, after which the generation begins, and typical growth rates, which confirm that small-scale dynamo is usually faster that large-scale one. However, our analysis of spectral characteristics has shown that the question about scales is more complex for Kazantsev dynamo than expected. For example, from maximum of correlation functions at small scales does not follow the maximum of these functions at large wave numbers, and from gauss-type, distribution in r-space does not follow the same distribution in k-representation. Using numerical calculations and asymptotic results, we try to answer on the question what should be considered as small and large scales for such dynamo and how small-scale generation can be taken in account in a large-scale process.

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MAGNETOCONVECTION IN A VERTICAL DUCT WITH DOWNWARD FLOW AND STRONG TRANSVERSE MAGNETIC FIELD

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A downward flow in a vertical duct with heating from the side and transverse magnetic field is studied numerically. The work is motivated by the design of liquid metal blankets for a tokamak fusion reactor where strong magnetic field and strong heating flux are present. The configuration considered in this work is related to the DCLL (Dual Coolant Lead Lithium) blanket module with poloidal ducts, in which liquid metal is pumped downward and the main component of the magnetic field is perpendicular to the flow direction. Strong heating flux is deposited at the wall facing the reaction chamber. The vertical duct is long with square cross-section, and walls are assumed to be thermally and electrically insulated except one wall subjected to constant heating flux. In the asymptotic limit of strong transverse magnetic field, the flow is assumed two-dimensional (see [1]). Direct Numerical Simulations (DNS) is used. The computations are conducted for the liquid metal flows at $Pr = 0.0321$ (LiPb alloy at 570 K), Reynolds number $5000 \leq Re \leq 10^5$, Grashof number $10^6 \leq Gr \leq 10^{10}$ and Hartmann number $10^3 \leq Ha \leq 10^4$.

In the downward flow within an insulated duct and strong heating at one wall, the mean temperature of the fluid grows downstream along the duct, so the flow is unstably stratified. The flow is found to be stable or unstable depending on the strengths of the heating and magnetic field. Based on the parametric study of the instability, a stability threshold can be estimated by the parameter $Gr/(HaRe)$ with critical value being around 4 (see [2]).

In the stable regime of the flow, the buoyancy effect influences the flow by changing the flow structure to be asymmetric but it is not significant enough to result in an instability. When buoyancy effect is significant, a pair of vertical jets is formed with one jet directed upward near the heated wall and the other directed downward in the bulk. The jets could not be observed due to their three-dimensional instability and breakdown without the magnetic field. In our configuration, the jets are stabilized by the strong magnetic field, although they become unstable to two-dimensional perturbations at some parameters. In the unstable regime of the flow, patterns of the developed flows are complex and diverse. The properties of the unstable flow cannot be reliably identified by a single group parameter. The parametric study shows that all three independent parameters Gr, Ha and Re are important. As discussed in [2], the flow patterns can be roughly classified into three types. The results also suggest that the flow is likely to be unstable with high-amplitude temperature fluctuations at the conditions typical for a fusion reactor blanket.

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HEAT TRANSFER IN ROTATING RAYLEIGH–BÉNARD CONVECTION IN PRESSURED SF_6

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Heat transfer in a rotating flow is of fundamental research interests to many geophysical and astrophysical phenomena, such as convective motion in arctic ocean, in the Sun and in the planetary atmospheres etc. The flow in such system sometimes shows a similar feature to the liquid metal flow moving in a magnetic field which is known as the 'two-dimensionality'. Due to Joule dissipation the flow variation along the magnetic field is suppressed and can even becomes two-dimensional in the bulk when magnetic field is strong. Similarly but with different mechanism, rotation can also change the flow to be gradient free along the rotating axis according to Taylor-Proudman theorem, and instead of traditional turbulent flow, a more two-dimensional flow with vertical vortices dominating appears when rotation is rapid. Accordingly, the heat transfer is expected to be modified by the rotation and most likely to be suppressed when the rate of rotation is sufficiently large. However, depending on the strength of the rotation, the heat transfer is not always suppressed, but sometimes, can be enhanced within certain range of rotation rate. Previous numerical and experimental studies revealed that the flow can be in three typical regimes depending on rotation rate, and the enhancement sets in ascribed to Ekman pumping, i.e. hot and cold plumes are stretched into vertical vortices sucking fluid out of the thermal boundary layers and enhance the heat transfer [1]. Many studies have been conducted to study the turbulent rotating Rayleigh-Bénard convection (RBC) systems at large Pr ($Pr > 1$, e.g. water, glycerol) [2,3] and small Pr (e.g. Helium and sulfur hexafluoride) [4,5]. In this work we extend the study of flow at low $Pr = 0.8$ in wide range of rotating rate and Ra: the convective Rossby number Ro variates from 0.02 to 50 and Rayleigh number ranges from 10^8 to 10^{10}. Pressurized sulfur hexafluoride (SF_6) flows in a cylindrical cell of the diameter-to-height aspect ratio 1/2 was investigated by means of Direct Numerical Simulations (DNS). Effects of rotation on heat transfer were analyzed by looking into the dynamics of the large-scale circulation, the properties of boundary layers, the long-term bulk temperature statistics and the global heat flux. Moreover, we consider the temperature dependence of the fluid properties which allows us to compare the results with the large-scale rotating RBC experiments in the "Uboot" of Göttingen in the same fluid and similar Rayleigh numbers. The possibility to determine how heat transfer in rotating RBC changes with rotation rate under non-Oberbeck-Boussinesq (NOB) conditions is discussed.

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PECULIARITY OF TAYLOR'S AND WAVY VORTICES INITIATION IN THE INSTABILITY STUDY OF THE CONDUCTING LIQUID FLOW, GENERATED BY A ROTATING MAGNETIC FIELD

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Stationary instability of axisymmetric laminar flow of a viscous conducting liquid in the infinitely long circular cylinder, arising under the influence of coaxially rotating magnetic field (RMF) of any rotary symmetry, has been investigated. The nearest analogue of the conducting liquid flow raised by the rotating magnetic field is Couette flow between two concentric cylinders from which internal one rotates and external remains motionless. Analyzing stability of similar type of flow, Lin [1] has noticed, that the first approximation equations for small disturbances of velocity and pressure allow periodic solution with respect to φ and z:

$$f = f(r) \exp(\sigma t + in\varphi + iaz),$$

where a is the real (dimensionless wave number), and n is the integer number. Usually deal with a special case of rotary symmetry $n = 0$. In this case a primary flow is independent of φ, but perturbations of velocity u_r, u_φ, u_z and pressure p are not zero. This problem has been investigated in detail. Calculations have shown, that the secondary flow is realised in the form of system periodic meridional vortices along a vessel's axis - so-called Taylor's vortices. Calculations reveal a one-vortical (in radial direction) pattern of Taylor vortices. Case $n \neq 0$ corresponds to the occurrence of the so-called wavy vortices when waves propagate along the axes of Taylor's vortices. The problem of stability of a primary azimuthal flow concerning occurrence of Taylor's vortices, and wavy vortices of different orders for one pair of poles ($p = 1$) of the RMF is considered in [2]. Expanding the area of this problem parameters for any symmetry of the RMF is considered in [3]. The problem is solved for two cases: in low-frequency approach and for any value of relative frequency. With the use of Galerkin's method the curves of neutral stability corresponding to occurrence of Taylor's and wavy vortices are calculated. It is shown, that Taylor's vortices at $p = 1$ arise in wide enough, but limited range of flow parameters, but upon the increase in parameters, they lose stability and convert to wavy vortices. It is established, that under certain conditions the loss of stability of a primary flow leads to the direct appearance of wavy vortices of some order, by-passing a stage of Taylor's vortices. On the curve of neutral stability separating area of one-dimensional azimuthal flow from the region of a three-dimensional vortical flow, points of bifurcation, corresponding to transition from a secondary flow in the form of Taylor's vortices to a secondary flow in the form of wavy vortices with $n = 1$ and with consecutively higher orders of a sinuosity, are defined further. It is characteristic, that such transitions are accompanied by step-wise increase in wave number, i.e. transition to smaller and smaller scale vortices. Such a cascade of bifurcations is observed as on the branch of the neutral stability corresponding to low-frequency approach, and on the branch corresponding to the case of arbitrary values of relative frequency. With increase in the order of rotary symmetry of the RMF ($p = 2$) the range of parameters at which loss of stability of a primary flow leads to occurrence of Taylor's vortices, is reduced. At $p = 3$ Taylor's vortices do not arise at all, and at once there are wavy vortices with $n \geq 1$. At $p = 3$ a zone of occurrence of wavy vortices with $n = 1$ is reduced, and at $p = 5$ wavy vortices appear already only at $n \geq 2$. The increases in values of Hartmann number, relative frequency and an order of rotary symmetry of the RMF reduce the characteristic size both Taylor's and wavy vortices. The vortices centre is thus displaced towards the cylinder wall.

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MODELING OF ROLLING PAD INSTABILITY IN LIQUID METAL BATTERY

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Magnetohydrodynamically induced interface instability in a liquid metal battery is analyzed. The battery is represented by a simplified system in the form of a rectangular cell, in which strong vertical electric current flows through three horizontal layers: the layer of a heavy metal at the bottom, the layer of a light metal at the top, and the layer of electrolyte in the middle. Two numerical models are applied: fully three-dimensional utilizing the OpenFoam solver and two-dimensional based on the shallow water approximation. It is found that in the case of small density difference between the electrolyte and one of the metals, the instability closely resembles the rolling pad instability observed earlier in the aluminum reduction cells. When the two electrolyte-metal density differences are comparable, the dynamics of unstable systems is more complex and characterized by interaction between two nearly symmetric or antisymmetric interfacial waves.

INTERNAL STRUCTURES AND RHEOLOGICAL PROPERTIES OF BIOLOGICAL FERROGELS

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Magnetic polymers (gels and elastomers) are composite materials consisting of nano-sized magnetic particles embedded into a gel matrix. Combination of rich set of physical properties of the polymer and magnetic systems is very perspective for many progressive industrial, bioengineer and biomedical applications. In part, these composites are used as magnetocontrollable dampers, vibration and shock absorbers. Hydrogels with biocompatible magnetic particles are very promising for various biomedical technologies — for drug delivery and biosensors; construction of soft actuators and artificial muscles; for regenerative medicine and tissue engineering. An overview on the synthesis of magnetic hydrogels and their biomedical applications can be found in [1]. Nonmagnetic biocompatible hydrogels are actively used in bioengineering and clinical medicine as scaffolds for manufacturing, curing and regeneration of biological tissues [2]. The scaffolds, prepared of magnetic hydrogels, have several advantages in front of their nonmagnetic analogies. First, magnetic particles allow in-vivo visualization of the growing tissue, by using the magnetic resonance imagining. Second, as some experiments demonstrate, the particles stimulate proliferation of the tissue cells. Third, in vivo applications, magnetic particles functionalized with the agents of the tissue growth, can be attracted to the magnetic scaffold, providing intensification of this process. Fourth, in-vivo, magnetic hydrogels can be injected into the place of the tissue regeneration in a liquid state, with the help of a syringe, i.e. by the microinvasive way. The gel, up to its curing, can be fixed in this place by using magnetic field of necessary configuration. Next, rheological properties and behavior of these magnetic implants can be controlled by the external field. The above-mentioned advantages of the magnetic hydrogels in front of the nonmagnetic ones attract considerable interest of researches and bioengineers to these systems. Many works have been devoted to the manufacturing, study and practical use of magnetic biological hydrogels. However, in spite of these efforts, fundamental features of many physical properties and behaviour of these materials are still unclear. Furthermore, there are still many challenges from the viewpoint of the design of magnetic hydrogels. First, most magnetic hydrogels, reported in the literature, are based on polymers cross-linked covalently. These hydrogels are usually very robust, but at the same time too rigid to allow tunability of their biomechanical properties at a large degree by application of magnetic fields. Furthermore, the pore size of covalent hydrogels is usually reduced, which hinders the diffusion of nutrients and oxygen and the removal of waste in biomedical applications. On the other hand, physically cross-linked hydrogels present a large pore size, adequate for applications, but unfortunately they are usually too weak from the biomechanical viewpoint and they lack of the required microstructure - they are usually microscopically inhomogeneous. In view of this, present and near-future efforts in the field of magnetic hydrogels should focus on the preparation of hydrogels with adequate internal order, biomechanical properties and with magnetic field-responsive behaviour. In this work we present a review our recent progress on the field of the experimental study and theoretical modeling of the rheological properties of magnetic gels based on three types of biological polymers – fibrin, alginate and peptide as well. Experiments show that elastic modulus of these systems fast, much faster than it is typical for ordinary composites, increase with concentration of the embedded particles. Strong magnetorheological effects (dependence of rheological properties on applied magnetic field) has been detected for all studied biological ferrogels.

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SHEAR MODULUS OF ISOTROPIC FERROGELS

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Ferrogels are modern smart materials, consisting of magnetic nano — or micron-sized magnetic particles distributed in a polymer matrix. Combination of the properties of polymer materials with a high response to the magnetic field offers great opportunities in the various high-tech areas, such as magnetically controlled dampers and shock absorbers, sensors, artificial muscles, scaffolds for growing of biological tissues and cell cultures. One of the most interesting features of these materials is their ability to change shape and rheological properties under the action of an external magnetic field. These magnetorheological effects have been studied in many experimental works; however lack of their theoretical analysis restrains progress in the field of study and application of these materials. We present results of theoretical study of effect of an external magnetic field on shear elastic modulus of the composites with non-linearly magnetized particles randomly and isotropically distributed in an elastic matrix. To avoid intuitive constructions with uncontrolled accuracy and adequacy, we restrict ourselves by the approximation of two interacting particles, which, as a rule, leads to good agreement with experiments till 10-15% of the particles volume concentration. Our results show that the modulus increases and tends to a saturation when the field increases.

INFLUENCE OF DIPOLE-DIPOLE INTERACTIONS ON THE CHARACTERISTIC TIMES OF BROWNIAN MAGNETIC NANOPARTICLES RESPONSE TO THE ARBITRARY TIME-VARYING FIELD

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There are numerous studies which devoted to dynamical magnetic response of ferrofluids to oscillating external field with arbitrary amplitude. The most of theoretical researches consider a ferrofluid as an ideal superparamagnetic "gas" whereas the present work is focused on the effects of interparticle dipole-dipole interactions. Ferrofluid is modeled as a monodisperse system of uniformly magnetized spherical particles suspended in a cylindrical container. It is assumed that the direction of a magnetic moment can change due to the rotation of the nanoparticle as a rigid body (Brownian mechanism). Dynamical spectra is obtained via solution corresponding Fokker-Planck-Brown equation. Two methods of solution, namely finite-difference numerical method and effective field approximation are used and results are compared. The susceptibility spectra are analyzed in detail in terms of the low-frequency behavior of real and imaginary parts and the position of the peak in the imaginary part. It yields three characteristic times of the magnetic response process. For the case of noninteracting particle in Debye-like spectra these three characteristic times have the same values at low field strength. If dipole-dipole interaction is taken into consideration the characteristic times scientifically differ from ideal case in the region of low values of field amplitude. These times tend to zero with growth of field strength, which is similar with the case of noninteracting particles.

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