INVESTIGATION OF THE LIQUID METAL MOTION IN THE VICINITY OF NEEDLE GRID CAUSED BY THE INTERACTION OF THE TERMOELECTRIC CURRENTS AND MAGNETIC FIELD INTERACTION.

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In the project numerical simulation of the temperature field and thermoelectric current distribution has been carried out for the interface between two media with different thermal conductivity and Seebeck coefficients. The current source in this case is the potential difference which is caused by the temperature gradient on the interface. In the case of the dendrit like crystallization the temperature gradient on the interface can reach considerable values causing the current flow from the dendrite tip to the basement or in opposite direction depending on the ratio of the absolute thermo EMF of the phases. By applying external magnetic field it is possible to to create liquid phase motion which changes the energy and concentration distribution in the vicinity of the crystallization front. This has influence on the structure of solidified sample.

Experimental setup is made from cobalt needles and InGaSn alloy to investigate macroscopic evidenc of these phenomena and to estimate flow character. Experiments have been carried out to investigate the flow of InGaSn in the vicinity of the needle. Motion is created by applying magnetic field which interacts with thermoelectric current which is appering on the boundary between both media (thermoelectromagnetic convection (TEMC)). Free surface deformations and temperature distribution measurements have been made at different values of magnetic field.

Numerical simulation of this process has been made to compare with experimental data. The role of numerical simulation is also to relate the macroscopic experimental results to the microscopic scale of the dendritic crystallization phenomena. Two and three dimensional models for temperature and termoelectric current distribution calculation have been developed. Flow calculations for different needle arrangements and orientations of magnetic field have been made using meshes of varying degree of refinement. These numerical results give an insight on TEMC dependence on the magnetic field at different length scales and how good is the agreement with simplified analytical estimations. Applied magnetic field results in induced currents, creating braking force on the liquid phase. This force is proporcional to the square of the magnetic force, but the TEMC is proportional to the first power of force, thus there exists the magnetic field value at which the flow intensity reaches the maximum. For a case of 3 mm diameter needle the theoretical prediction agrees well with numerical results and confirmed the tendency of decreasing flow at magnetic field values higher that some critical value.

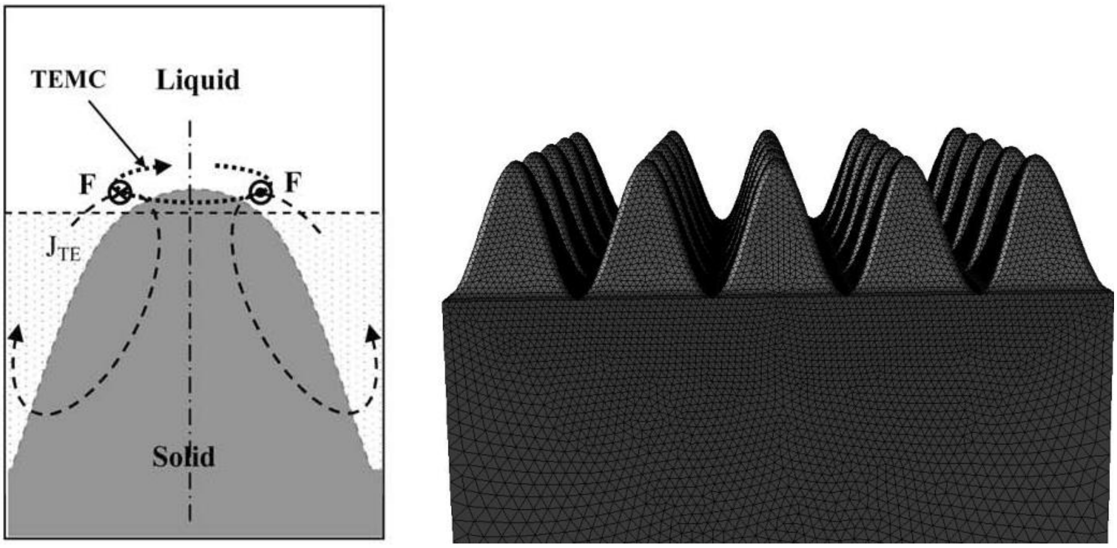

Fig.1. TEMC flow around one dendrite (from [1]) and created dendrite system geometry with surface mesh.

Another numerical model has been developed to investigate the similarity of the flow caused by applied current interaction with magnetic field and TEMC (Fig.1.). Such a flow can amplify or suppress the TEMC or create similar flow in case when TEMC is not existing. A three dimensional model is developed for a system consisting of 25 dendrite needles (Fig.2.). The results confirm the similarity of current induced flow with TEMC. Axial magnetic field interacting with current in the same direction, creates fluid rotation around each dendrite needle, but perpendicular magnetic field creates one vortex in the size of crucible (Fig.3., 4.).

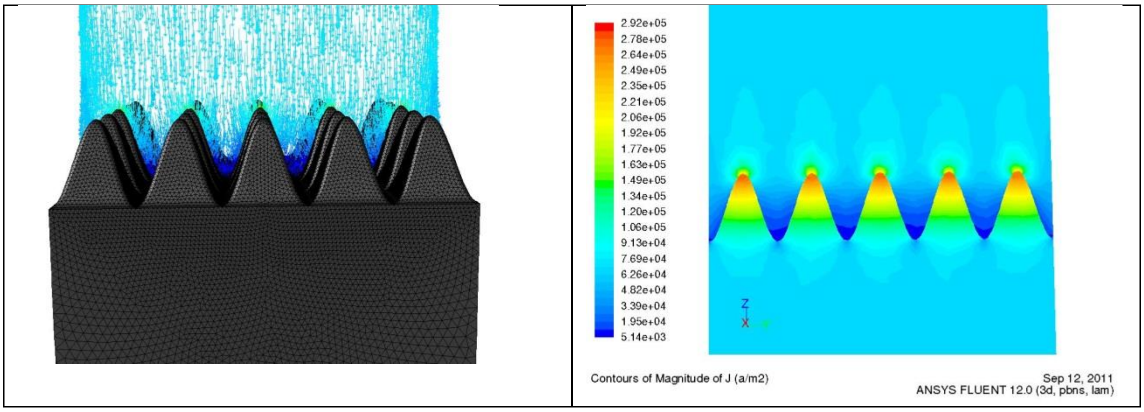

Fig.2. Current density vectors and magnitude in the plane *x*=0.

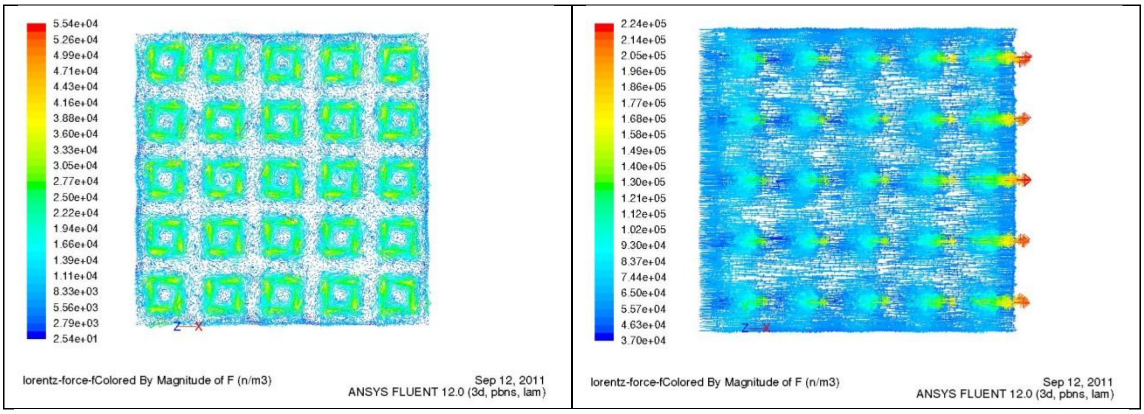

Fig.3. Lorentz force density at B_z=1T and B_y=1T in plane z=0.

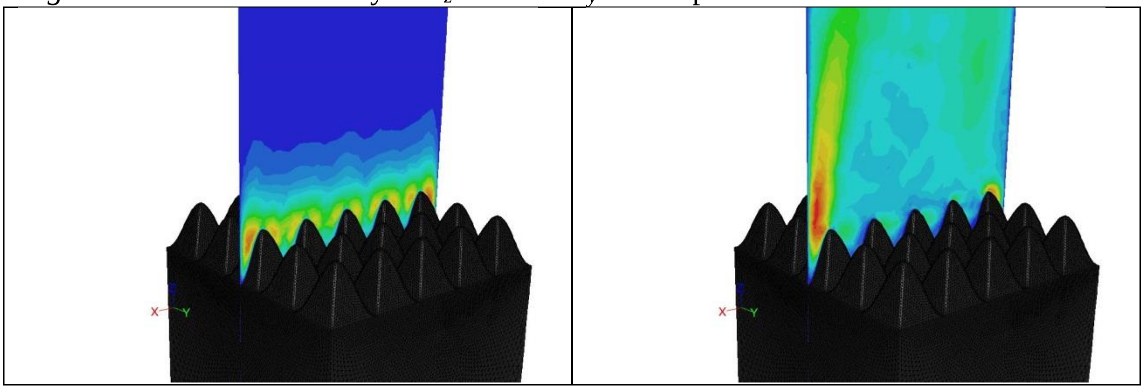

Fig.4. Velocity magnitude at B_z=1T and B_y=1T in plane y=0.

In this case the similarity with TEMC is determined by the fact that the Lorenz force appears only in the vicinity of boundary caused by the difference in the electric conductivities of solid and liquid phase. The results form I.Kaldre PhD thesis „Thermoelectric current and magnetic field interaction influence on the structure of binary metallic alloys” under cotutelle sheme with University of Grenoble (France) and are presented in papers [2-6].

In the framwork of project several mathematical models for neutron spallation target have been developed. These models include heat generation due to the proton interaction with target heavy metal nucleys. Models are developed using ANSYS Fluent software with User Defined Subroutines in C language for volumetric heat sources.

The developed liquid metal target is compared with ESS 2003 base target model (Fig.5.). The ESS target is characterised with complicated construction and complex liquid metal flow structure with three inlets; side inlets form the base flow and the middle one though a narrow slit ensures window cooling. The proposed target has much simpler geometry and more predictable flow, resulting in a three times lower pressure drop at the same flowrate.

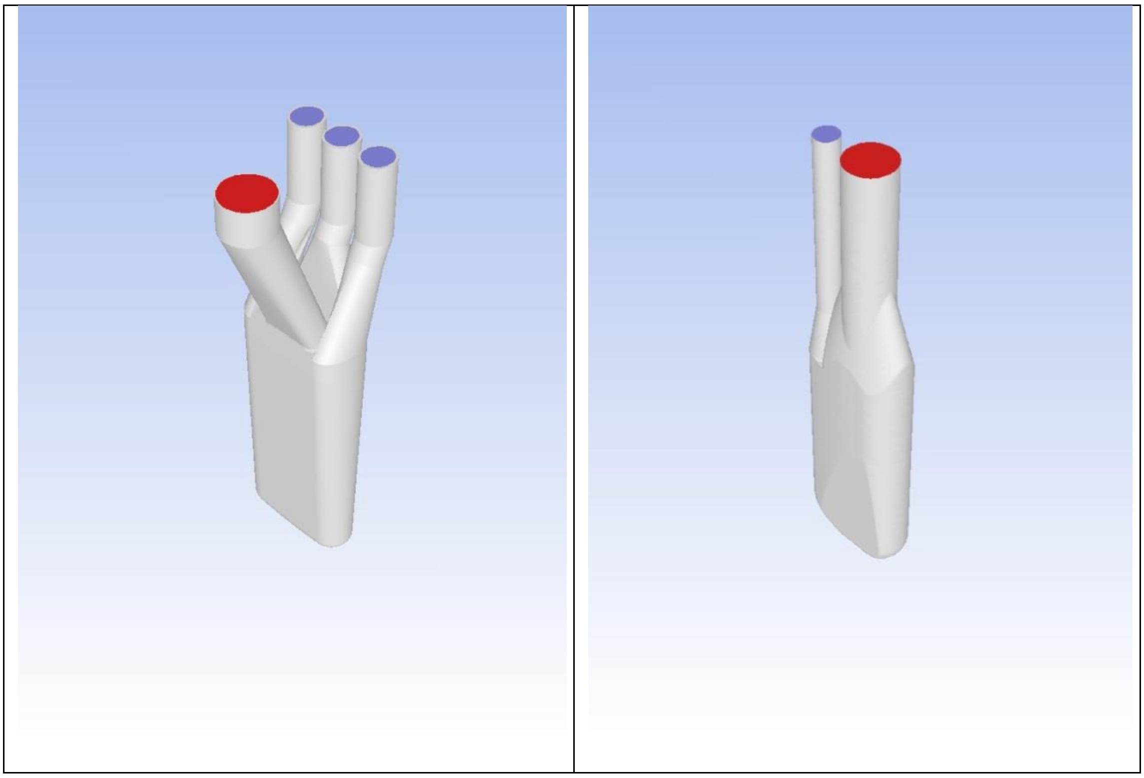

Fig.5. Proton target geometry. Blue denotes liquid metal inflow, red outflow. Left is ESS 2003 base design, right proposed target.

Along with liquid metal targets, several solid target options have been considered. The potential advantage of solid target is a possibility of use metals with very high density, like tungsten. In this case there is a wide choice of possible coolant options. As coolants traditionally liquid or gases have been used, which is a case of high or medium Prandtl numbers. The use of liquid metals as coolants in this application has several advantages. One of them is high thermal conductivity of liquid metals, another is related to the liquid metal property to act not only as a coolant, but also as a spallation media, thus incresing the neutron yield from the unit volume. Finding the optimal target construction is a non trivial task, thus there is a considerable interest in different target designs.

The considered solid phase geometry comprises periodic system of rods (Fig.6.) or spheres. The system of periodic rods has been used in Paul Scherrer institute target SINQ with water cooling. Comparing two coolant options – water and gallium (Fig.7.) shows tha advantage of using liquid metals as coolants as it results in considerably lower temperature differences at smaller flowrates.

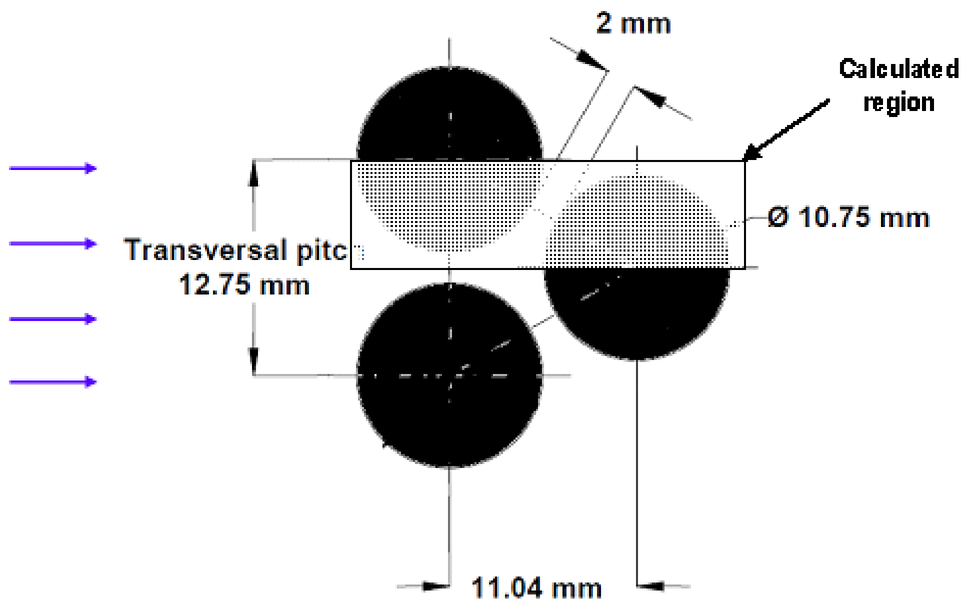

Fig.6. Calculation region which takes into account periodic arrangements of rods.

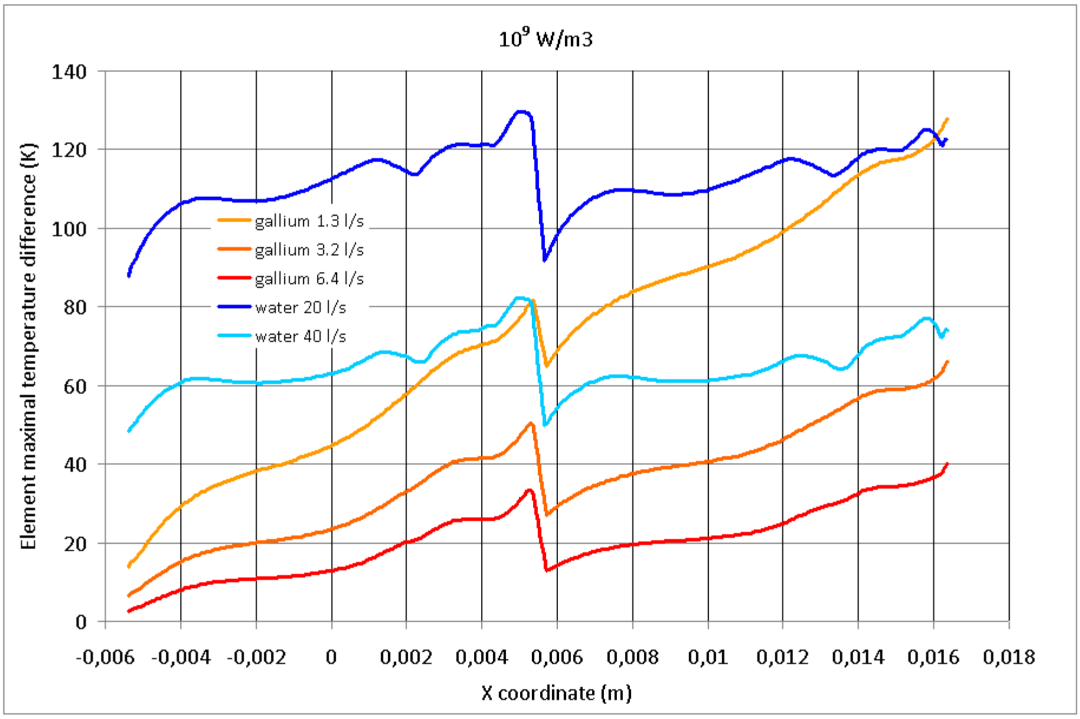

Fig.7. Temperature difference distribution on the rod surface for water and gallium cooling.

The results have been reported in conferences [7,8], in collaboration with Paul Scherrer intitute (Switzerland) several papers are in preparation [9].

In the framwork of project several mathematical models for electromagnetic induction pumps (EMIP) have been developed. Models are developed using ANSYS Fluent software with Magnetohydrodynamics (MHD) module and User Defined Subroutines in C language for travelling magnetic field for different ELIP design options.

The developed models allow to define arbitrary magnetic field distributions which approximate the magnetic field in real pumps. The possibility to define linear travelling magnetic field wave has been extended to the cylindrical geometry for rotating field in radial (Fig.8., 9.) or axial directions.

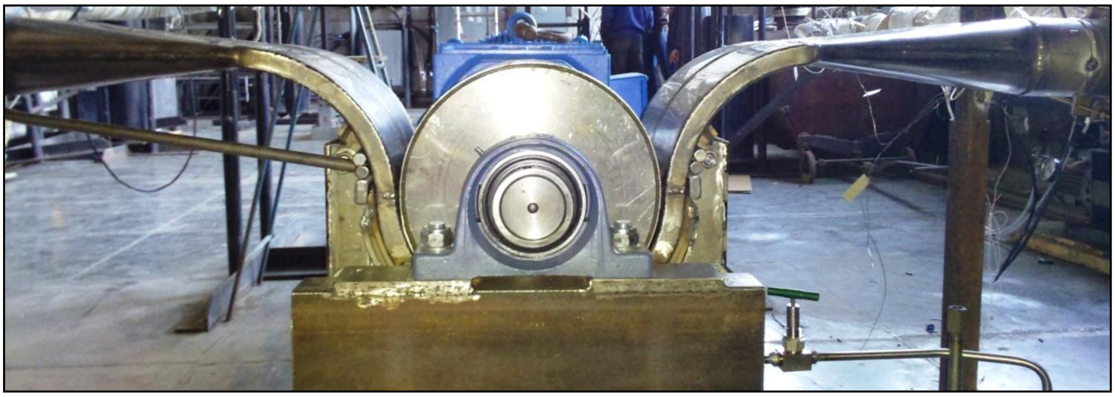

Fig.8. EMIP and experimental loop build in Institute of Physics University of Latvia.

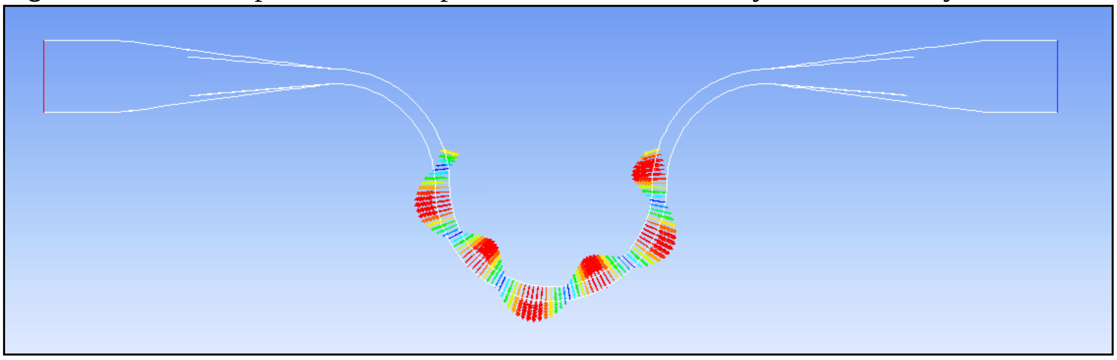

Fig.9. EMIP model with travelling (rotating) magnetic field.

These models allow to investigate effects which previously have not been accessible, like liquid metal circulation in linear pump with zero flowrate (Fig.10.). The reason for circulation is the nonhomogeneous electromagnetic force distribution over the channel width. While this effect has been mentioned in literature, the methods for estimation of the influence on the pump performance have not been elaborated.

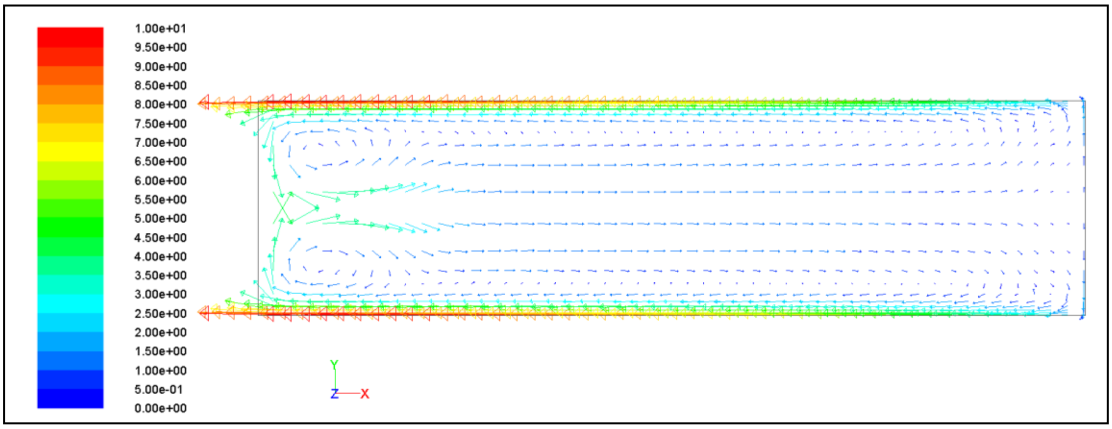

Fig.10. Velocity vectors at zero flowrate and observed circulation.

The numerical results for a model of linear EMIP without conductive walls have been compared with developed analytical solutions for the case of zero flowrate. This comparison for the developed pressure difference dependence on the magnetic Reynolds number (Fig.11.) and (Fig.12.) shows good agreement and confirms the applicability of the developed numerical models.

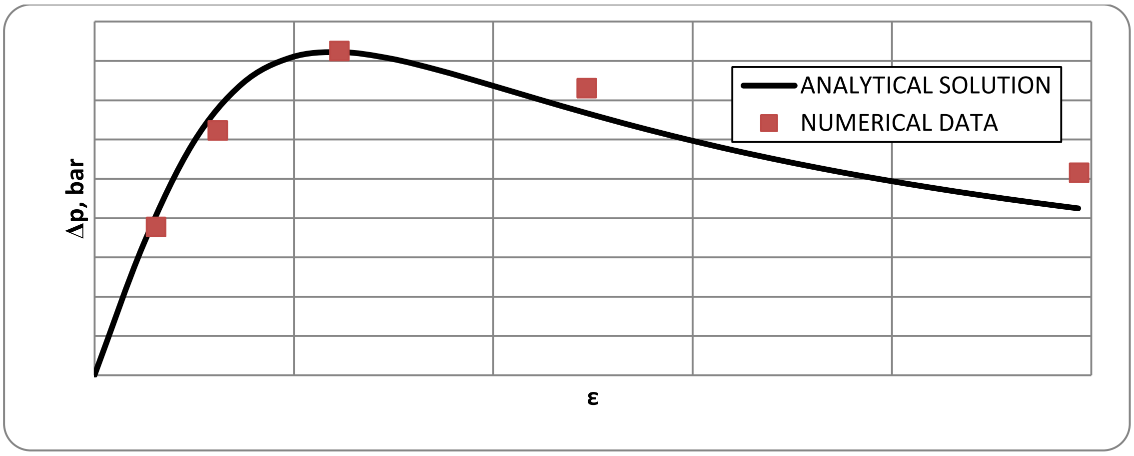

Fig.11. The developed pressure difference vs magnetic Reynolds number.

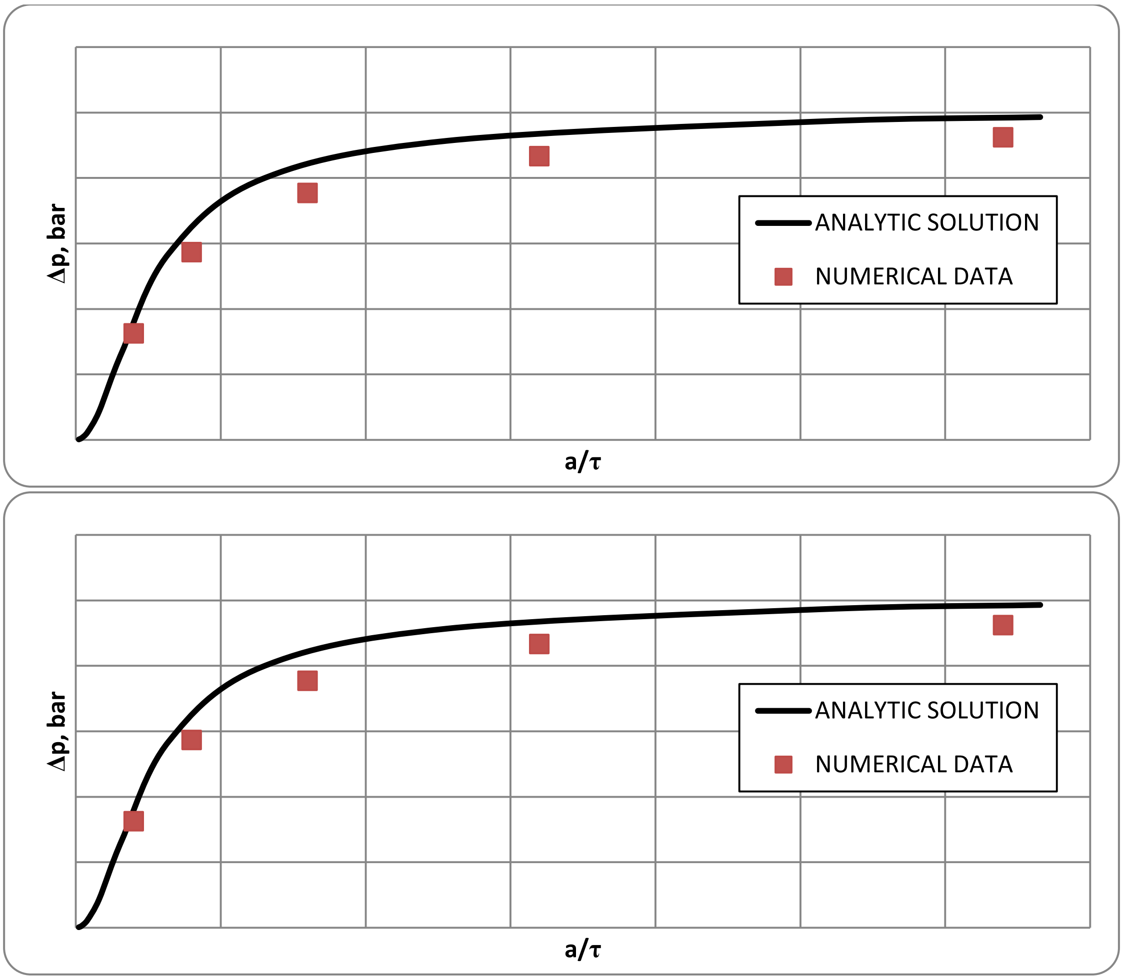

Fig.12. The developed pressure difference vs channel width and magnetic field wavelength ratio.

The developed numerical models more universal and apart from the description of processes in EMIP can be applied also for the modelling more wide class of MHD problems, like mixing of melt which is an important technological process in metallurgy.

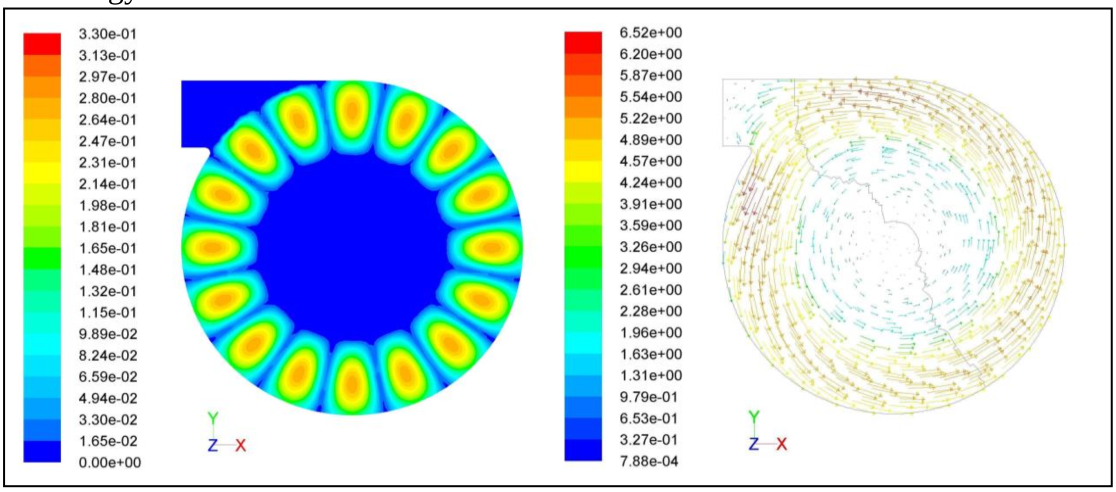

Fig.13. Centrifugal EMIP rotating magnetic field distribution defined with developed UDF (left) and calculated velocity vectors (right).

The analytical and numerical (Fig.13.) results have been used in L. Goldšteins master’s thesis „Centrifugal electromagnetic pumps with permanent magnets for liquid metal transportation" and was evaluated as „excellent". The thesis results are reflected in paper [10].

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