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Heat transfer of the uranium sphere in laminar cooling flow

Abstract. The key problem in the construction of new geometrical and structural type of nuclear reactor of forth generation is optimized cooler configuration. In the present paper the mathematical model of the uranium sphere located in intensive neutron flux and streamlined by laminar cooling flow is presented. Detailed picture of the temperature difference and hydrodynamic velocity and its pressure of the cooling flow around the sphere heated inside by nuclear fission reactions are analyzed. The emergency cases in nuclear reactor operation are mainly connected with the cooler heat transfer from active zone, where fuel elements are located to the steam generator when cooler transport is stopped due to unexpected interruption or its leakage. The paper reveals some definite parts of the technical problem from analyzing it's appearing to the ways of its full solution.

Keywords: heat transfer, laminar flow, uranium sphere, nuclear reactor, cooling flow.

Introduction

The detailed review of the behavior of different reactor systems in emergency situations is one of the first and obligatory steps in the design of every nuclear power plants. Evaluation of the consequences of hypothetical accidents requires the calculation of the dynamics of nuclear, physico-chemical and thermal-hydraulic processes during the development of such types of accident [1]. While projection of nuclear power systems is mandatory review of the behavior of different reactor systems in emergency situations: when a device failure, damage of cooler system, in the rupture of pipelines, pumps, etc In the first stage to solve this problem a mathematical model should be created which will be normally operated and governed by existing technologies, then this model will introduce various types of disturbances reflecting violations of the forecasted processes, as well as any new processes taking place only in case of accidents. Usually hypothetical accidents of nuclear reactors are described by creating of a very complex mathematical models using high-performance computing. These models are the result of many years of large groups of scientists working and the application will certainly need to solve the aforementioned technical problems (accident prevention and the development of measures to eliminate them) associated with the economy of the process. One of the most important aspects of security (reliability) of nuclear system is cooler system, which damage will cause of emergency situations. This side of nuclear reactor safety problem the present paper is focused.

Main equations

The velocity spacedistribution ($\vec{V}$) around the sphere is given in [2] and equals to the following

$$\vec{V} = -\frac{3R}{4}\frac{\vec{u}+\vec{n}(\vec{u}*\vec{n})}{r} - \frac{R^3}{4}\frac{\vec{u}-3\vec{n}(\vec{u}*\vec{n})}{r^3} + \vec{u}\,, \qquad (1)$$

where R-radius of the sphere, r -spherical coordinate, $\vec{u}$ - the sphere velocity vector.

The pressure in its boundary region is defined as follows:

$$p = p_0 - \frac{3}{2}\eta\frac{\vec{u}\vec{n}R}{r^3}\,, \qquad (2)$$

where η– viscosity.

For time dependent flow and temperature dependence velocity and temperature space dependence in the heated nearby region we have the following basic equations

$$\rho\frac{d\vec{V}}{dt} + \rho(\vec{V} * \nabla) = \nabla\left[\rho + \mu\left(\frac{dV_i}{dx_k} + \frac{dV_k}{dx_i}\right)\right] + \rho\vec{g}\,, (3)$$

$$\rho C_p \frac{dT}{dt} + \rho C_p \vec{V} * \Delta T = \nabla(\chi \nabla \mathrm{T}) + \frac{\mu}{2\mathrm{C_p}} \left[\frac{dV_i}{dx_k} + \right.$$
$$\left. + \frac{dV_k}{dx_i}\right]^2 + W(x, y, z), \qquad (4)$$

where ρ–are the density of the flowing liquid, C_p– liquid's heat capacity, μ – flow velocity, T – temperature, W – sphere energy generation power.

Boundary conditions:

$$\vec{V}(x_0, y_0, z_0) = 0\,, \qquad (5)$$

$$T(x_0, y_0, z_0) = T_{Wall}(x_0, y_0, z_0)\ , \qquad (6)$$

where x_0, y_0, z_0 heated sphere surface.

Mathematical model calculation

Mathematical model was created from uranium sphere which located in the middle of the cylinder, which streamlined by laminar cooling flow. The initial temperature of uranium sphere is 1000(C), temperature of cooling flow is 0(C). Also we assume that the uranium sphere generates about 2 000 (W/m^3) of heat. Across the boundary condition the velocity of flow is zero (u = 0) and heat transfer is not occur $n * (k\Delta T) = 0$. The radius of uranium sphere is 0.3 meters, radius of cylinder is 1 meter and height is 6 meter. The pressure in the cylinder is 11 000 (Pa). On the one side of cylinder water enters with pressure 20 000 (Pa), on the second side water go out with pressure 10 000 (Pa) and from both side delivery flow rate equal 0.1 (m^3/s). The following pictures describe the temperature and velocity (figure 1) on the cylinder after 1 second of cooling liquid starts its motion.

It is clearly shown that heat transfer (figure 2) from the sphere is maintained due to viscosity of the coolant and might be evaluated in the loop system of the cooling liquid around the active zone of nuclear reactor. The increase of nuclear fission intensity increases the boundary layer where heat transfer is most efficient.

The pressure (figure 3) and temperature violation on the reactor compound constructions will be used to predict its future operational characteristics such as helium accumulation and hardness of bearing construction materials

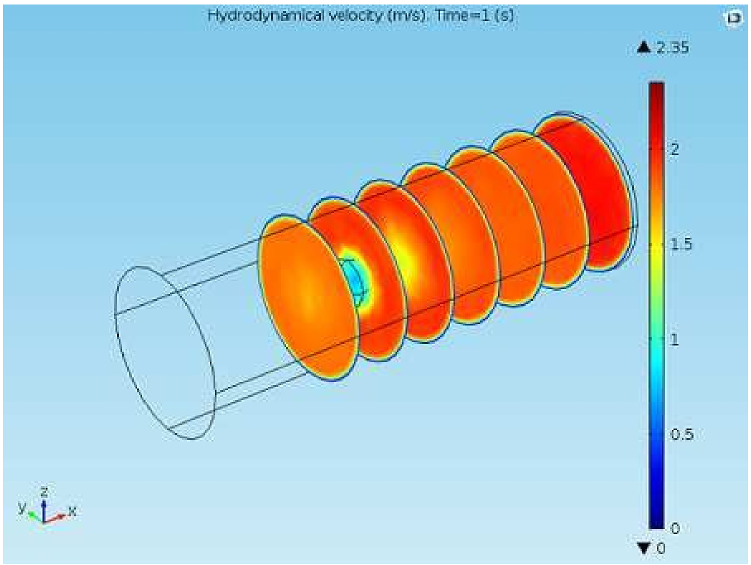

Figure 1– Hydrodynamic velocity of the cooling liquid as time dependent function in the boundary region

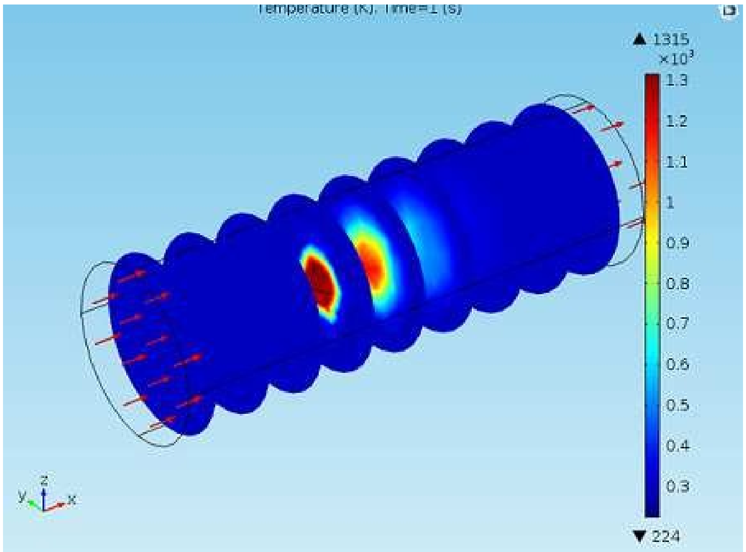

Figure 2– Temperature distribution of the cooling liquid around the heated sphere at higher intensity of neutron flux

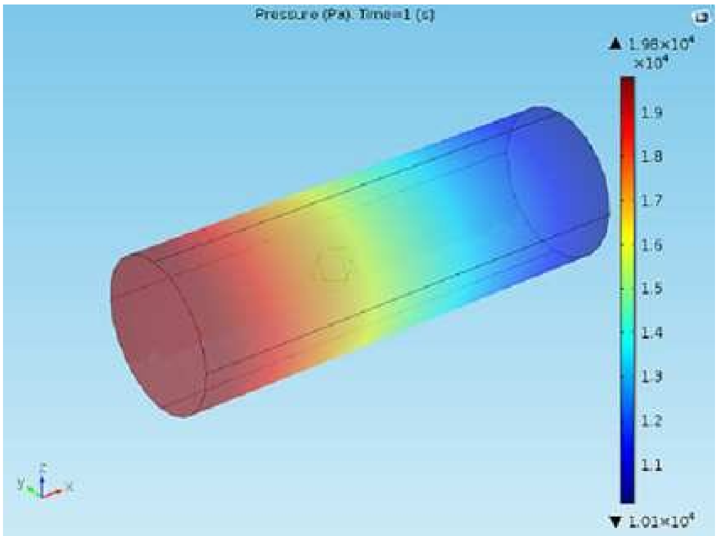

Figure 3 – Cooling liquid pressure distribution around the sphere thermal source

Conclusion

In the present paper the thermal characteristics of the nuclear plant station are analyzed and temperature distribution in such types of moving liquids in intensive heat producing physical objects of some definite geometry is highly important for optimal technical design of nuclear reactors of forth generation. High temperature gas cooling reactors of small power output are very needed in industry not due to its advantages in safety systems but also to its simple construction facilities. But to find effective cooler speed in such type of reactor is one of the main problems which should be further more studied and analyzed.

References

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