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QUASI INCOMPRESSIBLE FLOWS IN THE IRIS REACTOR PRESSURIZER

Perinaldo Severino Júnior[1a], Gustavo Koury Costa[2], Carlos A. Brayner de O. Lira[1b], Mário Augusto B. da Silva[1c], Antônio Carlos de O. Barroso[3]

[1] Universidade Federal de Pernambuco – Departamento de Energia Nuclear
Av. Prof. Luis Freire 1000 Cidade Universitária
50740-540 Recife, PE
a: perinaldojr@hotmail.com
b: cabol@ufpe.br
c mabs250@yahoo.com.br

[2] Centro Federal de Educação Tecnológica de Pernambuco
Av. Prof. Luis Freire 500 Cidade Universitária
50740-540 Recife, PE
gustavokoury@cefetpe.br

[3] Instituto de Pesquisas Energéticas e Nucleares (IPEN/CNEN-SP)
Av. Prof. Lineu Prestes 2242
05508-000 São Paulo, SP
barroso@ipen.br

ABSTRACT

The behaviour of the velocity field associated to water flows between the core riser and the pressurizer in the IRIS (International Reactor Innovative and Secure) reactor is of prime importance for the analysis of reactivity transients in such a reactor. This work dealt with the solution of quasi incompressible flows in the above mentioned part of the IRIS reactor. The governing equations employed to describe the water flow were the Navier-Stokes equations, adapted for quasi incompressible flows. The mass conservation equation was re-written in order to account for the fluid bulk modulus, which led to the obtainance of a relation between the pressure and velocity fields. The energy equation, in its turn, was decoupled from the complete Navier-Stokes system. The resulting equations were then discretized with the aid of a Streamline-Upwind Petrov-Galerkin Finite Element Method (SUPG). The obtained results for an in-surge with two different hole diameters turned out to be consistent and we believe that such results may be used in the design of the actual IRIS facilities.

1. INTRODUCTION

If there is no equilibrium between the power supplied by the IRIS reactor core and the power used in its steam generator, then the temperature of the primary flowing fluid will vary. If this variation is such that the temperature increases, then the fluid will flow into the pressurizer IRIS chamber through the surge orifices (in-surge). On the other hand, if the temperature decreases, an out-surge takes place. Modeling such surge flows with the aid of CFD techniques allows for establishing the influence that the surge-fluid velocity magnitude and geometrical dimensions of the IRIS pressurizer chamber, have on the thermohydraulic behaviour of the pressurizer. The physical model employed for accomplishing this was the Navier-Stokes equations. Although the energy equation might also have been solved by using the results from the velocity and pressure fields , it was not done here.

2. MATHEMATICAL BASIS

The quasi-incompressible Navier-Stokes equations in a vector form, can be written as follows:

$$\rho \frac{D\boldsymbol{u}}{Dt} = \rho \boldsymbol{f} - \nabla p + \mu \nabla^2 \boldsymbol{u} \tag{1}$$

$$\frac{1}{c^2}\frac{\partial p}{\partial t} + \rho \nabla^T \boldsymbol{u} = 0 \tag{2}$$

where ρ is density, D/Dt is the, so-called, material derivative operator, $\boldsymbol{f}$ is a body force field, ∇ is the gradient operator, p is pressure, μ is the fluid absolute viscosity, $\boldsymbol{u}$ is the velocity field, ∇^T is the divergence operator, c is the speed of sound into the medium, t is time and ∇^2 is the Laplacian operator. Equation (2) represents the conservation of mass re-written in terms of the fluid bulk modulus.

The set of momentum and continuity conservation laws expressed in Equations (1) and (2) can be re-written in the advective-diffusive form, as shown in Equation (3).

$$\boldsymbol{B}\boldsymbol{U}_{,t} + \frac{\partial \boldsymbol{F}^k}{\partial x_k} - \frac{\partial \boldsymbol{D}^k}{\partial x_k} - \boldsymbol{Q} = \boldsymbol{0}, \; with: \quad \boldsymbol{B} = \begin{pmatrix} \boldsymbol{I}_{nd\times nd} & \boldsymbol{0}_{nd\times 1} \\ \boldsymbol{0}_{1\times nd} & (\frac{1}{\rho c^2}) \end{pmatrix} \tag{3}$$

The x_k is the $k-th$ component of the position vector $\boldsymbol{x}$, nd denotes number of spatial dimensions, $\boldsymbol{F}^k$ is the advective flux and $\boldsymbol{D}^k$ is the diffusive flux. In the present approach the source term $\boldsymbol{Q}$ was not accounted for.

The Finite Element variational formulation was executed by employing a Petrov-Galerkin weighting function, in the context of the SUPG stabilized method, which led to the weak form of the problem. The final discrete set of linear equations was obtained from that weak form, by considering elementwise operations on the SUPG matrices involved, as it is usually done [1]. A Predictor-Multicorrector method was used for solving the resulting system of linear equations [2].

3. IRIS PRESSURIZER CHAMBER

Figure (1) depicts the IRIS pressurizer chamber (left - a) as well as its lower, cylindrical-shaped part (right - b) geometrical dimensions. The lower part will be termed here “IRIS pressurizer chamber basis” for simplicity.

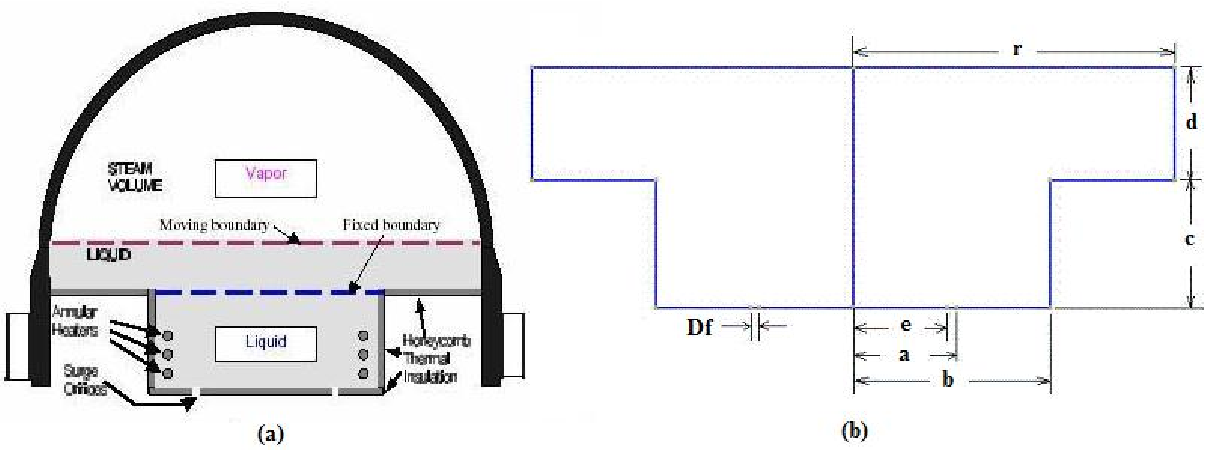


Figure 1. a - The IRIS pressurizer layout; b - geometrical dimensions

The values of the geometrical dimensions for the IRIS chamber basis, as illustrated in Figure (1-b), that have been considered in this work are in accordance with [3]. These values are specified in Table (1).

Table 1. Geometrical dimensions

Df	e	a	b	c	d	r
0,030	0,783	0,813	1,596	1,034	0,921	2,605
0,070	0,763	0,833	1,596	1,034	0,921	2,605

All dimensions in meters

One can see that two diameters were considered for the surge orifices, denoted by Df in Figure (1-b). These two dimensions gave rise to two designations for the geometrical configurations which were related in this work as: geometry $Df-30$ (referred to $Df = 0{,}030\,m$) and $Df-70$ (referred to $Df = 0{,}070\,m$). The flow through the eight surge orifices was considered, in accordance with [3], as $5{,}4 \times 10^{-4}\ m^3/s$. Accounting to this value of total flow and to the diameters of each geometrical configuration, the resulting values for the in-surge jet velocities are $0{,}089\ m/s$ for $Df-30$ and $0{,}016\ m/s$ for $Df-70$. As for the fluid physical properties, it was considered that $\mu = 7{,}57 \times 10^{-5}\ N\,s/m^2$, $\rho = 625{,}29\ kg/m^3$ and $c = 703{,}38\ m/s$, with μ the absolute viscosity, ρ the density and c the speed of sound into the medium. These values of the fluid physical properties were obtained by taking the average of the properties at the primary circuit conditions (namely $1{,}5 \times 10^7\ N/m^2$, $593\ K$) and at the saturated fluid at $1{,}5 \times 10^7\ N/m^2$.

4. BOUNDARY CONDITIONS FOR THE IN-SURGES

The considered boundary and initial conditions can be better seen with the aid of Figure (2).

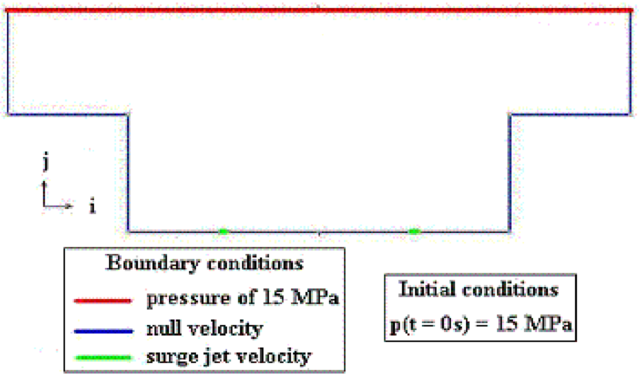
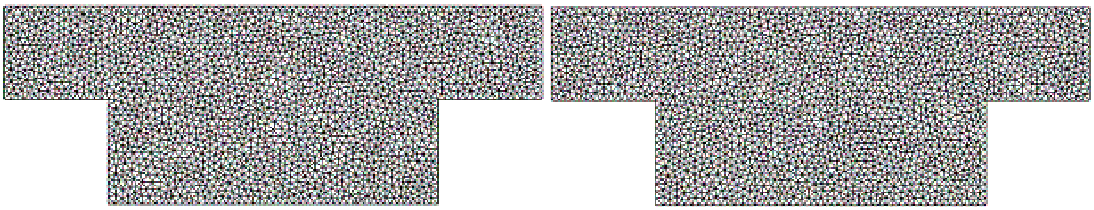


Figure 2. IRIS chamber basis - Boundary and initial conditions

The corresponding surge jet velocities for each IRIS pressurizer chamber basis geometrical configuration has already been specified in section 3.

5. COMPUTER SIMULATION

The geometrical domain constituted by the IRIS pressurizer chamber basis was discretized by using triangular finite elements. The two non-structured meshes can be seen in Figure (3).



Configuration Df-30 - uniform mesh
3955 elements, 2087 nodes

Configuration Df-70 - uniform mesh
3934 elements, 2075 nodes

Figure 3. IRIS pressurizer chamber basis - meshes

The resulting pressure fields ,for both meshes shown in Figure (3), were approximately constant all over the domain. Indeed, the variation in the pressure fields obtained did not exceed the order of $10^{-4}\ N/m^2$, which is really little as compared to the nominal value of $1{,}5 \times 10^{7}\ N/m^2$. The behavior of the euclidean norm of the residue vector associated to the Predictor-Multicorrector method was as depicted in Figure (4).

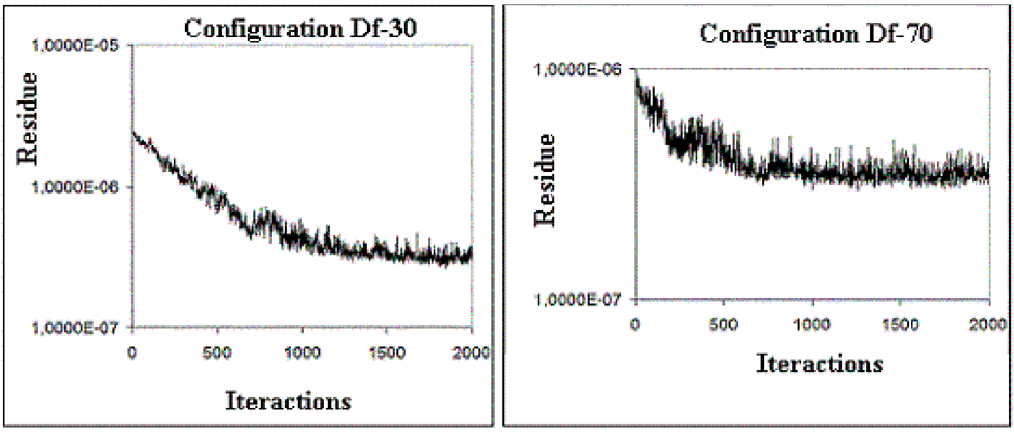


Figure 4. First computer experiment - variation of residue

The corresponding velocity vectors in this first experiment were as shown in Figure (5).

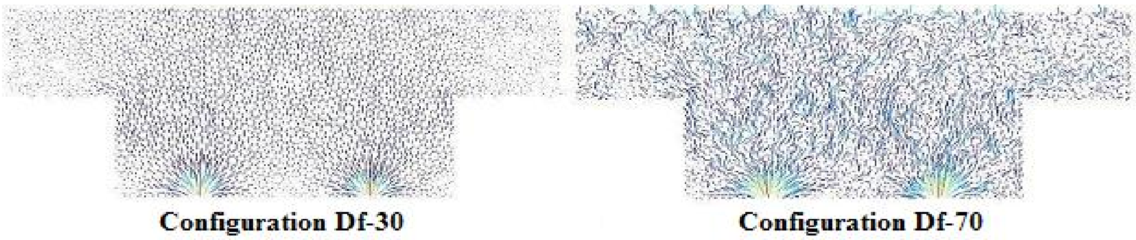


Figure 5. First computer experiment - spurious velocities

It can be readily seen from Figs. (4) and (5) that spurious results were obtained in this first computer experiment. It was so because of the large value of the prescribed pressure as compared to the value of the surge jet velocities. Since the pressure field turned out to be almost constant, i.e., its gradient nearly vanished, new homogeneous boundary and initial conditions for pressure were considered ($p = 0 \ N/m^2$), without losing physical significance. As the simulation run once more, the following results represented by Figs. (6) and (7) were obtained.

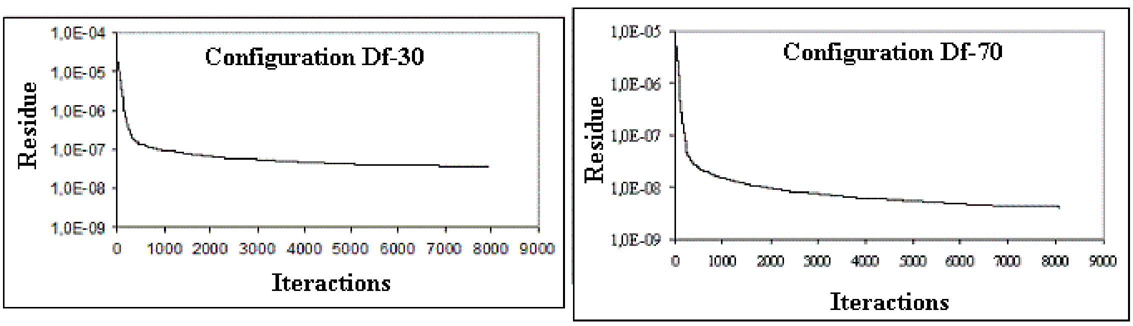


Figure 6. Second computer experiment - variation of residue

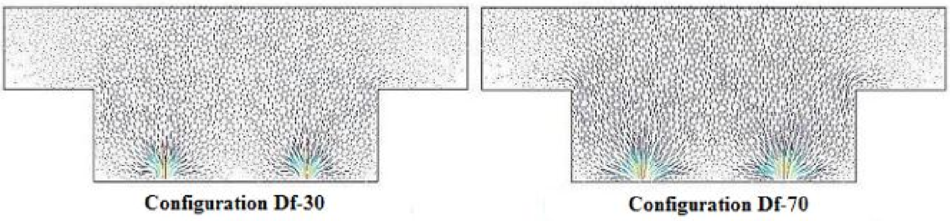


Figure 7. Second computer experiment - velocity vectors

6. CONCLUSIONS

The velocity vectors magnitude rapidly went to zero as the fluid went farther within the IRIS pressurizer chamber. It was so because of the small value of the norm of the in-surge jet velocities. The behavior of both configurations appeared to be quite similar. By employing the results obtained for the pressure and velocity fields plus an equation of diffusion of a substance other than the reactor fluid, it can be simulated, e.g., how Boron diluted into the fluid diffuses in the IRIS pressurizer chamber. This could enhance the role of Boron on the maintenance of acceptable power transients in the IRIS reactor core.

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