DESIGN OF A FLOW REDISTRIBUTION DEVICE FOR THE ANNULAR SECTION OF A REFLUX TYPE ELECTROMAGNETIC PUMP USING CFD

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INTRODUCTION: To ensure circumferentially uniform inlet velocity into the annular section of a reflux-type electromagnetic pump used for liquid sodium transport, a porous plate with graded porosity is proposed. The porosity distribution, expressed in terms of pressure drop coefficients, is derived and optimised with the help of detailed three-dimensional CFD analyses. Based on the optimised configuration, a manufacturable design was formulated and subsequently verified using numerical simulations.

1. OVERVIEW

The present work is carried out for the reflux-type ALIP (Annular Linear Induction Pump) being designed for pumping liquid sodium in auxiliary circuits of Indian sodium cooled fast breeder reactors [1,2]. The cross section of a typical ALIP with a flow capacity of 170 m^3/h is shown in FIG. 1.

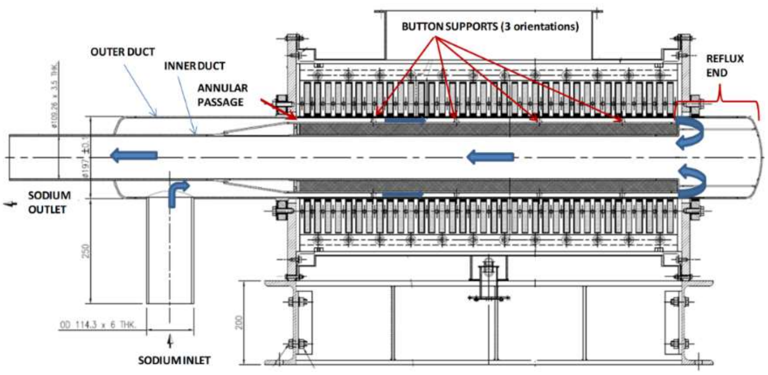

FIG.1. Schematic of a typical ALIP for a reflux type sodium cooled fast reactors [1]

The entry to the annular passage of the ALIP receives liquid sodium through a single radial nozzle, which then flows into a transition region (inlet plenum) between the inner and outer ducts. This leads to significant flow mal-distribution at the inlet of the annular portion. The pumping action in the form of electromagnetic forces arising out of the interaction between a traveling magnetic field and induced current in liquid sodium primarily occurs within this annular portion. Any flow maldistribution can lead to onset of magnetohydrodynamic instability within the annular portion [3]. In order to achieve a circumferentially uniform velocity at the entry, a plate with variable (sector-wise distributed) porosity is conceived and devised with the help of CFD studies. An initial set of parametric studies is done to derive and optimise the porosity distribution to achieve a uniform flow with minimal increase in hydraulic pressure losses. Further, the porosity distribution is translated into a porous plate design that can be manufactured and installed. The required porosity distribution is achieved with the help of circular holes distributed in the wall of a shell shaped like a conical frustum appropriately sized and spaced so as to closely respect the porosity distribution derived from earlier CFD studies. The final configuration is further verified with the help of CFD studies. More detailed aspects are discussed in the following sections.

2. CONCEPTUAL DESIGN

The initial part of the study focuses on developing a viable concept of a flow redistribution device. The proposed concept needs to minimize flow maldistribution while ensuring low pressure drop and ease of manufacturing. A graded porosity-based flow redistribution device shaped like the frustum was conceived with a half cone angle of 45° with maximum and minimum radii equal to those of outer and inner ducts respectively. The angle is provided to maximise the area of the shell to ensure ease of implementation of porosity. The study was initiated with 8 sectors (22.5° each) of different porosities distributed along the 180° sector. Porosities are distributed into discrete sectors to facilitate ease of manufacturing. Towards this, for the numerical studies done as part of the present work, a 180° three-dimensional CFD model of the ALIP is developed. The reference model (without any flow redistributor) is meshed using about 2.9 million hexahedral elements. The number of elements is determined after mesh independence studies. An isometric view of the CFD model developed along with important boundary conditions, sub-domains and a view of the mesh used is shown in FIG. 3.

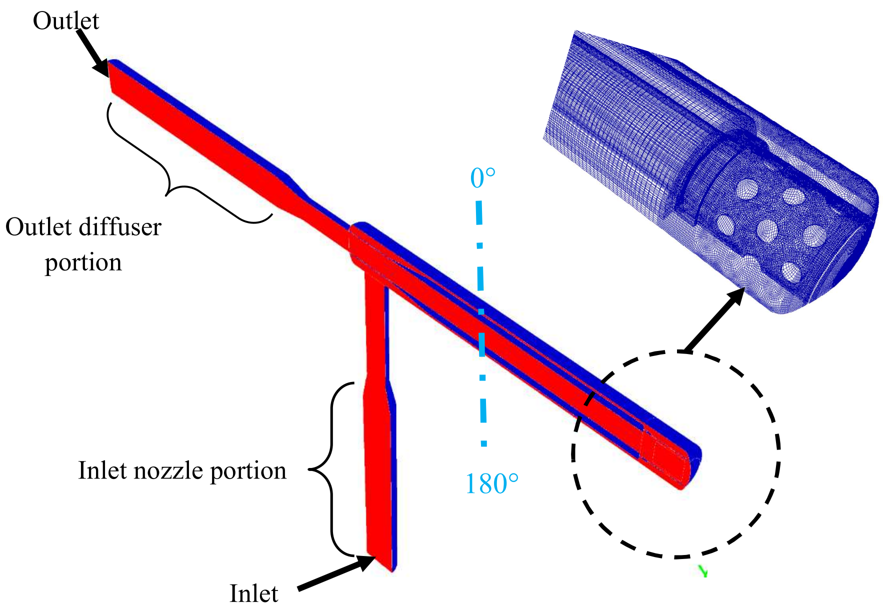

FIG.2. Three dimensional CFD model of ALIP

Additional structures are introduced in order to obtain a more realistic velocity distribution at the ALIP entry and exit. The volume flow rate considered for the present study is 120 m^3/h (expected flow rate in SSFDC). The fluid for these studies is liquid sodium at 250°C.

Once the solution for the reference model is obtained, the graded-porosity conical shell is incorporated into the CFD model, as illustrated in FIG. 3. Subsequently, parametric CFD studies were carried out to determine the optimal sector-wise porosity distribution for the flow redistribution device. The final optimised configuration enabled condensing the porosity distribution to 4 sectors along with removal of one sector of 22.5° in the bottommost portion. Such a configuration is found to be adequate for achieving a uniform flow at annulus inlet and further gradation in porosity has minimal impact. The effect of porosity on flow field is captured using a porous jump boundary. Over a 180° sector, four different porosities are imposed as shown in FIG. 3. In general, higher pressure drop across the conical shell would lead to higher reduction in flow non-uniformity. However, lower pressure drop is desirable as this would ensure a higher pump efficiency. The graded porosity approach allows a uniform velocity field with minimal pressure drop. For resolving pressure-velocity coupling, SIMPLE algorithm is used. Momentum equation is discretised using second order UPWIND scheme. The pressure equation is discretised using PRESTO scheme. To capture effects of turbulence, the realizable variant of high

Reynolds number k-ε model is used. Discretisation of k and ε equations is using second order UPWIND scheme. Flow equations are solved using FLUENT v 19.0.

The derived optimal distribution of porosities (pressure drop coefficients) is presented as part of FIG.3 (inset). With this configuration the difference between maximum and minimum velocities (circumferential variation of radially averaged velocities) reduces from 2.4 m/s to 0.3 m/s. The hydraulic pressure drop of the ALIP increases by 8 kPa which is insignificant as compared with developed head of 400 kPa. The conceptual design is converted into a detailed design with the help of variably distributed circular holes on 10 mm diameter in a 3 mm thick plate.

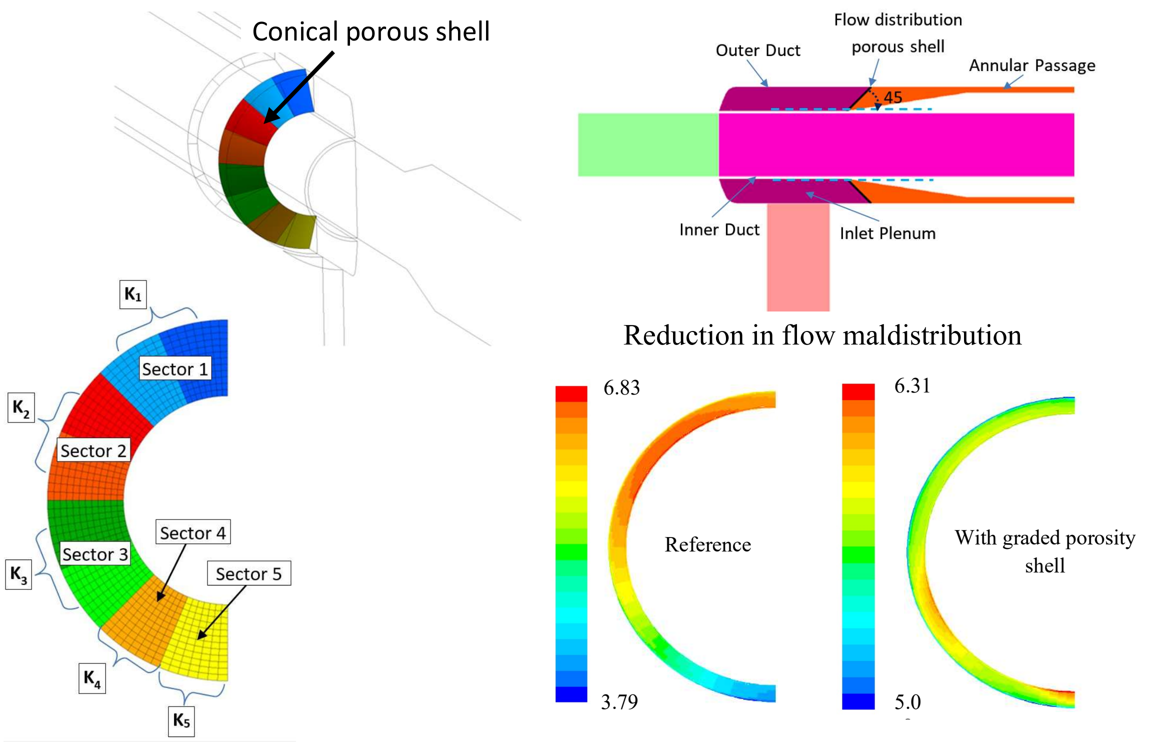

FIG.3. Modelling approach followed for design of FDD

3. DETAILED DESIGN

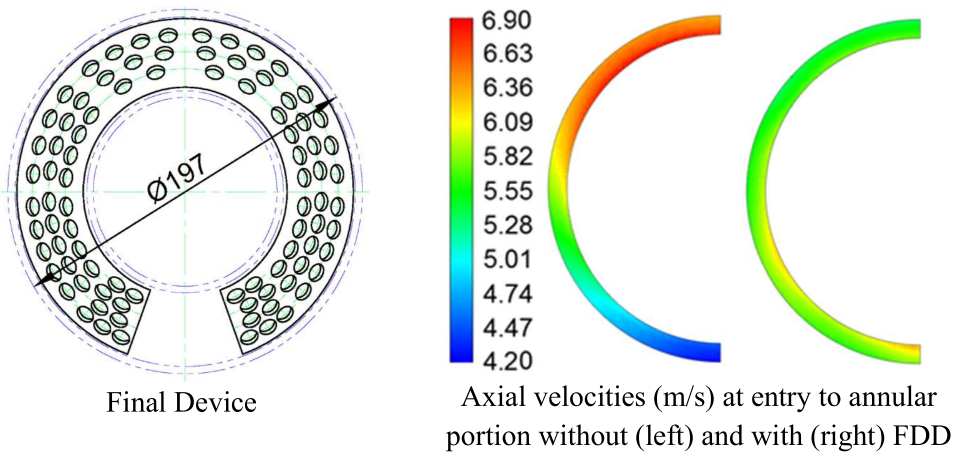

FIG.4. Derivation of detailed design and effect on flow field at annulus entry

Based on the conceptual design, an actual porous plate that can be manufactured and installed in the ALIP is devised and the same is numerically analysed and verified. The maximum hole size and number of holes are decided to match with the porosity requirement with limitation on minimal ligament length between holes and uniform spacing within each sector. The total number of holes is decided for each sector based on the correlation of Ward-Smith [5]. The minimum hole size is restricted to 10 mm to minimize flow blockage in the sodium flow path during long term operation.

From the CFD simulations, the mal-distribution in velocity at inlet to the annular portion is reduced significantly which is in line with porous formulation studies. Contours of velocity magnitudes and plots of radially averaged axial velocities with and without FDD are presented in FIG. 4 and FIG. 5 respectively. The significant reduction in flow maldistribution can be clearly seen. The standard deviation (about mean velocity) of radially averaged velocities at annulus inlet reduces significantly from 0.84 without FDD to 0.17 with FDD. This design will be validated in a water loop before implementation into the plant.

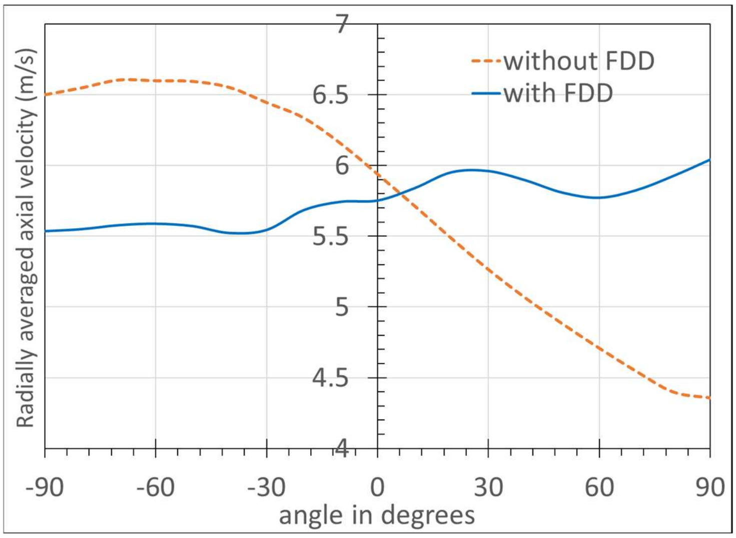

FIG.5. Circumferential variation of radially averaged axial velocity at entry to annular portion for flow of 120 m^3/hr

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