DESIGN OPTIMIZATION OF SURGE TANK HYDRAULICS OF SFR

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INTRODUCTION: In secondary sodium circuit of Prototype Fast Breeder Reactor (PFBR), a surge tank is provided to absorb the pressure surges in the secondary sodium loop. Surge tank has argon cover gas sapce above sodium column to absorbs the pressure surges. During normal operation of reactor, the disturbances in the sodium-argon interface in surge tank can cause argon gas entrainment into the sodium. The existence of argon in the form of bubbles in sodium can lead to operational difficulties in the reactor. Therefore, to minimize gas entrainment in the surge tank, passive devices known as Gas Entrainment Mitigation (GEM) devices are installed within the tank. These devices suppress free surface disturbances and mitigate gas entrainment during transient conditions at the expense of an additional pressure drop. In the present study, a new surge tank configuration incorporating an improved design of GEM devices is proposed to enhance performance. The effectiveness of this configuration was evaluated through experimental investigations using water model tests. The experimental results demonstrated significantly improved hydraulic performance, characterized by lower pressure drop and enhanced safety margin in the critical gas entrainment height.

1. OVERVIEW

The PFBR surge tank have two bottom inlets connected to the Intermediate Heat Exchangers (IHX) and four side outlets leading to the steam generators. Internally, the surge tank is equipped with a 20% open area porous plate and 30° inclined stiffener plates functioning as GEM devices [1]. These devices create a pressure drop within the system, which is 11.75 % of the head developed by the secondary sodium pump. Through detailed hydraulic studies, the surge tank geometry has been optimized to achieve minimum pressure drop and maintain a low critical sodium level to effectively prevent gas entrainment. In this study, a new surge tank configuration with side inlets and bottom outlets is proposed for investigation. Since the pressure surge absorption capability of the surge tank primarily depends on its overall volume and cover gas space, the tank sizing has been retained identical to the reference design. The present work focuses on modifying the internal hydraulic features of the surge tank to enhance flow distribution and mitigate gas entrainment more effectively. The development of the surge tank geometry for future FBRs were carried out through a systematic approach involving computational modelling, experimental validation, and performance assessment. GEM devices were developed using validated CFD models and tested through small-scale experiments. The hydraulic performance of final surge tank configuration was evaluated using a large-scale experimental model ensuring dynamic similitude with prototype conditions.

2. DEVELOPMENT OF CFD MODEL AND ITS EXPERIMENTAL VALIDATION

A 1/7.5th scale surge tank model (figure 1) with side inlet–bottom outlet configuration was fabricated and erected for experimental validation. A corresponding CFD model with identical geometry and flow conditions was developed to predict the flow pattern. The CFD model was validated by comparing the predicted velocity profiles with experimentally measured data from the scaled surge tank model [2]. The velocity profile inside the surge tank was measured using an Ultrasonic Velocity Profiler (UVP). Since most of the GEM devices employed in the surge tank are porous in nature, separate CFD validations were carried out for configurations with and without the porous devices. For validation purpose, a porous shell of 50% porosity was introduced in the model. A typical comparison between the experimentally measured and CFD-predicted velocity profiles at the free surface for Froude similitude flow rate and different level of water inside surge tank is shown in figure 2. The results indicate a reasonable agreement between the CFD predictions and experimental measurements.

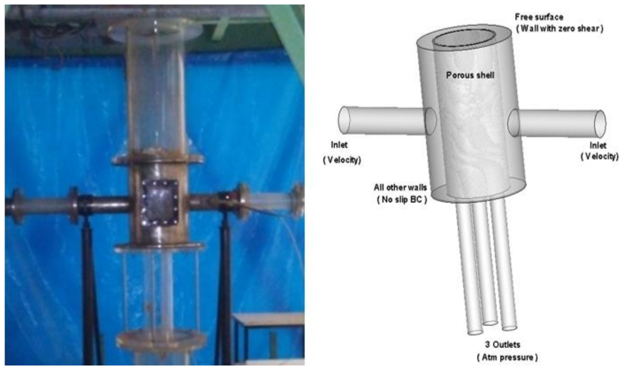

FIG. 1. Small scale model of surge tank and its CFD model

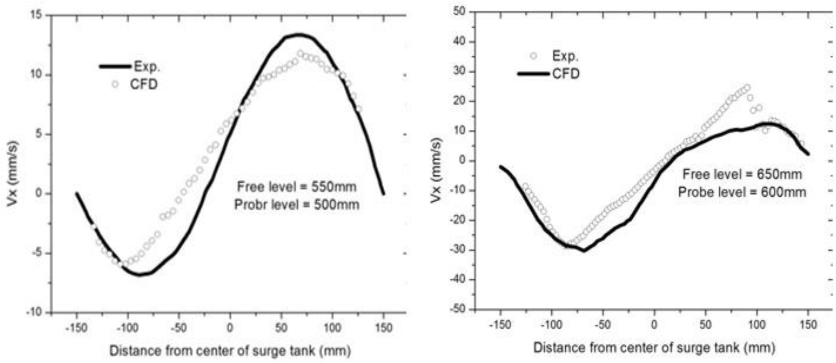

FIG. 2. Comparison of measured and numerically predicted velocity profile along radial direction inside ST

3. GAS ENTRAINMENT MITIGATION DEVICE DEVELOPEMNT

In the second stage of optimization, various GEM device configurations were analysed using CFD to study their influence on free surface parameters such as surface velocity, turbulent kinetic energy, turbulence intensity, and vertical velocity beneath the free surface. The GEM devices were designed with the objective of minimizing free surface disturbances while ensuring a low-pressure drop across the device. Among the various GEM designs studied, the conical porous shell (figure 3) demonstrated superior performance in minimizing free surface velocity, turbulent kinetic energy and turbulence intensity.

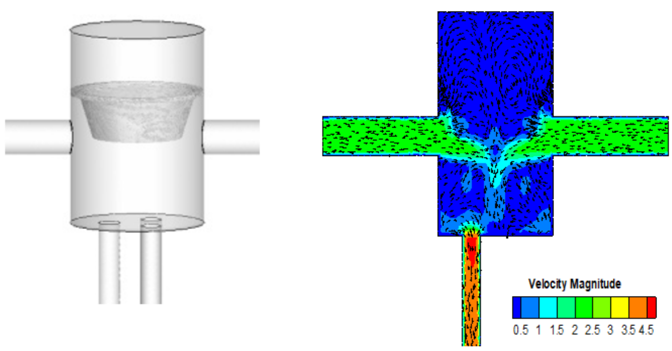

FIG. 3. CFD model of surge tank with conical porous shell and predicted velocity profile inside surge tank

Additionally, this configuration resulted in a lower pressure drop within the surge tank compared to the case without the conical shell. Hence, this device was fabricated and tested in the small-scale surge tank model. Experimental results showed that the introduction of a conical porous shell inside the surge tank reduced the critical height for gas entrainment by 40% approximately and additionally, the conical shell offered a reduction in pressure drop across the surge tank. Further investigations were carried out to assess the performance of the conical porous shell under non-uniform inlet flow conditions. In such cases, small surface vortices were observed in the free surface. To suppress these vortices and further stabilize the free surface, an additional device, a sheet matrix was introduced. The combination of the conical porous shell and the sheet matrix established superior performance in minimizing free surface disturbances.

4. FINAL PERFORMANCE TESTING IN 5/8 SCALE MODEL

The final stage of the present study involves the performance evaluation of new surge tank configuration with associated GEM devices using a 5/8 scale surge tank model (figure 4) simulating Froude number (Fr) and Weber number (We) and with water as the working fluid. Experimental results indicate that, with the introduction of the conical porous shell, there was an effective reduction of ~60% in the critical gas entrainment height.

FIG. 4. 5/8 scale model of surge tank and gas entrainment mitigation devices

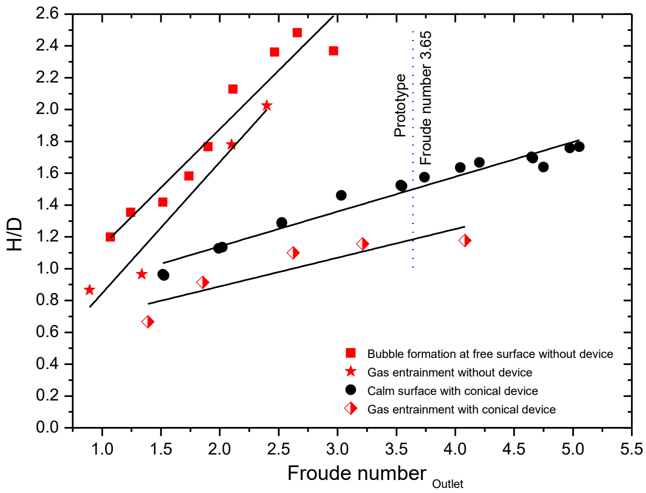

FIG. 5. Comparison of critical gas entrainment height inside the 5/8 scale surge tank model

However, for safe and smooth reactor operation, rather than critical height of gas entrainment, the liquid level corresponding to a calm free surface is recommended. The normalized critical liquid column heights against Froude number are plotted in figure 5. From the experiments, the non-dimensional critical height (H/D) for gas entrainment and calm surface in the 5/8 scale surge tank model are found to be 1.15 and 1.56 respectively. Maintaining the sodium level same as PFBR surge tank (3800 mm) ensures enhanced safety margins, where a large safety margin of 1270 mm is available to avoid gas entrainment and a margin of 370 mm is ensured for maintaining a calm free surface. The pressure drop characteristics of the 5/8 scale surge tank model have been evaluated over a range of flow rates and are presented in figure 6. At higher flow rates, the introduction of the conical porous shell does not impose any additional pressure drop; rather, a reduction of approximately 3% in pressure drop is observed. This reduction is attributed to the device acting as a flow guide, effectively directing the incoming jets towards the outlets and minimizing flow collisions. Although the sheet matrix introduces a localized pressure drop corresponding to its position (elevation), near the free surface its overall contribution to the system pressure drop is negligible.

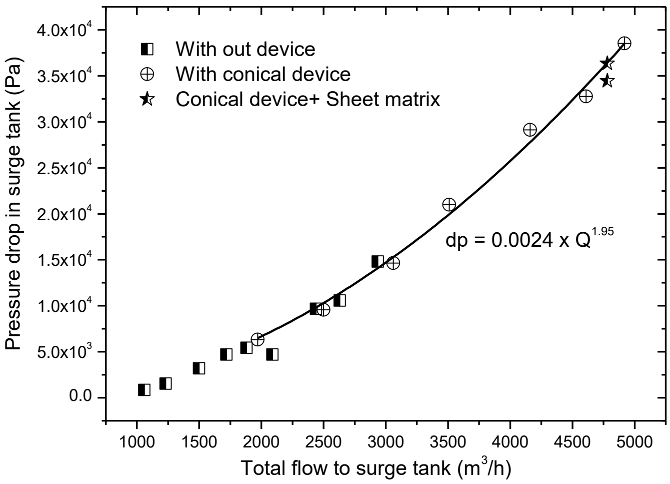

FIG. 6. The effect of devices on pressure drop in the system

Based on experimental results, the estimated pressure drop in the prototype surge tank is thus 0.326 bar, which corresponds to 6.2% of the head developed by the secondary sodium pump. This represents a substantial reduction in pressure drop compared to the PFBR surge tank, where the measured pressure drop was 0.62 bar. Therefore, the newly optimized surge tank geometry provides a pressure drop reduction of approximately 48%, leading to a corresponding reduction of about 5.5 % in power requirement of secondary sodium pump.

5. SUMMARY

The surge tank of PFBR, equipped with GEM devices, which offers a pressure drop accounting for 11.75% of the head developed by the secondary sodium pump. In pursuit of advanced design for future fast reactors, studies have been carried out to develop a surge tank configuration with improved GEM devices to achieve both reduced pressure drop and lower operating sodium levels without risk of gas entrainment. A new surge tank geometry with side inlet and bottom outlet configuration was proposed, integrated with two GEM devices: a conical porous shell and a sheet matrix. Analytical studies and small-scale water experiments indicated the effectiveness of this configuration in suppressing gas entrainment with minimal additional pressure drop. Subsequently final performance evaluation of this configuration of surge tank has been carried out using a 5/8-scale surge tank model using water. The experimental study, confirmed that the proposed combination of devices effectively mitigate gas entrainment from the free surface. The extrapolated results show a safety margin of 1270 mm is available to avoid gas entrainment. The pressure drop offered by the new configuration is 48% of pressure drop offered by PFBR surge tank, leading to an expected reduction of 5.5 % in pump power requirement.

REFERENCES

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