THERMAL HYDRAULICS STUDIES FOR FUTURE INDIAN FAST BREEDER REACTORS

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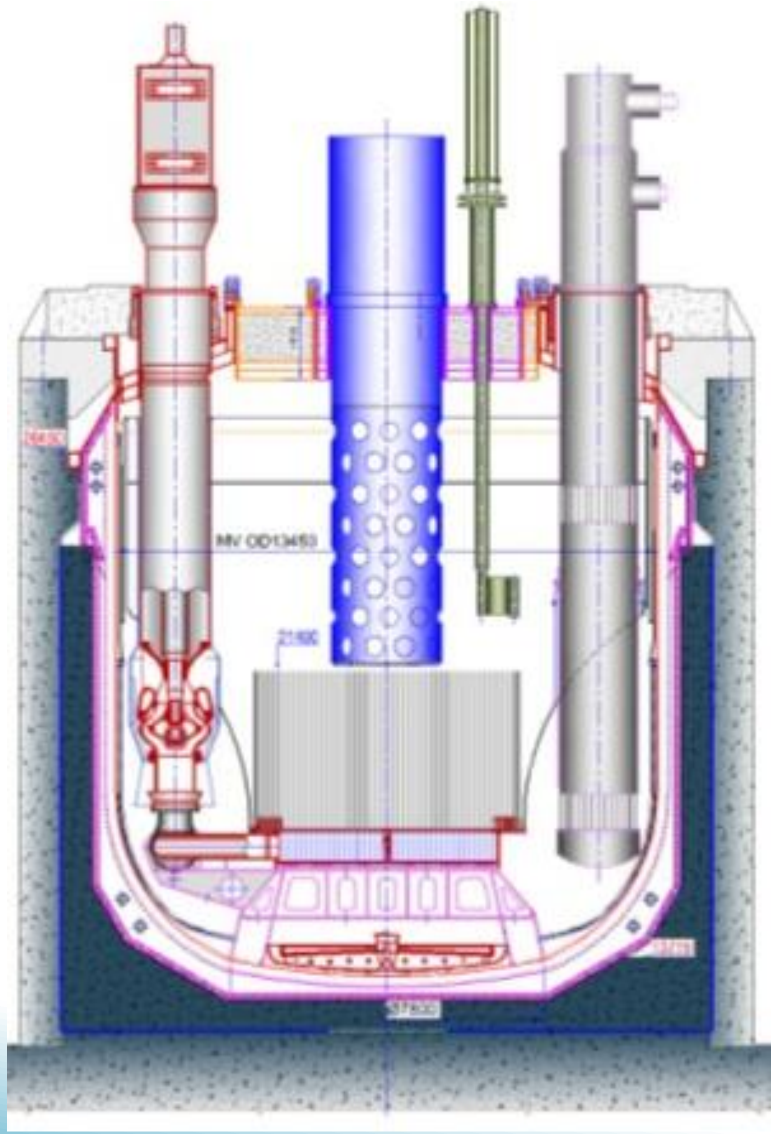


Vertical section of FBR1&2

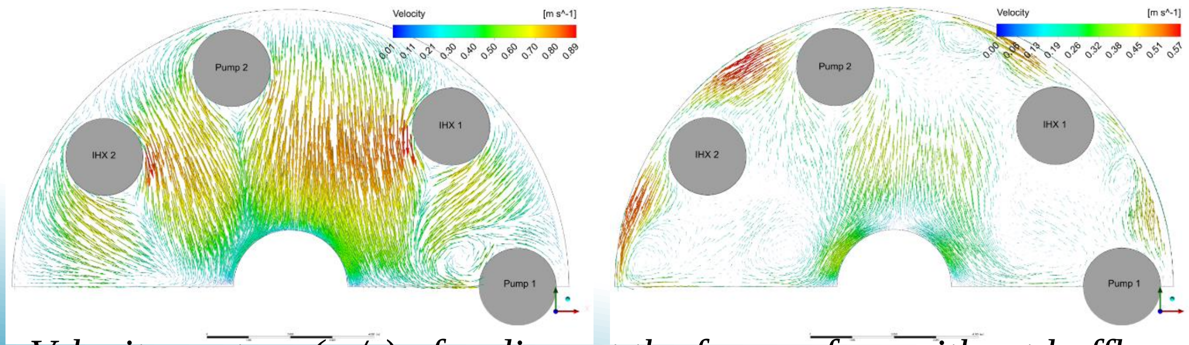
Introduction and Background

- Prototype Fast Breeder Reactor (PFBR) [1] is a 1263 MWt, 500 MWe sodium cooled pool type reactor presently under construction in Kalpakkam.
- The design for next generation higher capacity Fast Breeder Reactors (FBR1&2) has been commenced with enhanced safety and improved economy as the main targets.
- FBR1&2 is pool type reactor with many proposed innovative modifications to achieve specific targets like higher reactor power, core optimization for higher breeding ratio, specific material inventory reduction, simplified systems and components, integrated manufacture and erection, twin units sharing non-safety systems, reliability enhanced decay heat removal systems and enhanced in-service inspection and repair features.
- Due to the modified design, there are many dimensional and flow changes in reactor components.
- The design changes envisaged for FBR1&2 includes, (i) 3 sodium pumps, (ii)two primary pipe per sodium pump, (iii) inner vessel with single torus lower shell, and (iv) reduced main vessel diameter with narrow gap cooling baffles.
- This paper briefly discusses about the 3D Computational Fluid Dynamics (CFD) thermal hydraulics studies carried out for the FBR1&2

Results and Discussion

OPTIMIZATION OF ANTI-GAS ENTRAINMENT BAFFLES

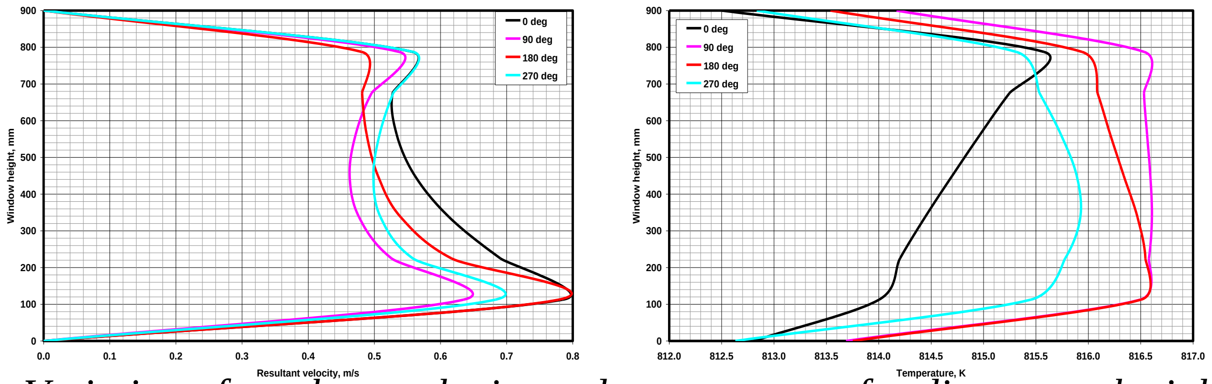
- The sodium inventory inside the reactor is divided by inner vessel (IV) into two portions, viz., hot pool and cold pool. There is an argon cover gas region above the sodium pools. The free surface is turbulent in nature and the maximum free surface velocity is to be limited to 0.5 m/s to avoid the entrainment of argon into sodium flow.
- The maximum free surface velocity can be limited by adding a baffle attached to the IV. The location of baffle and width of baffle influences the maximum free surface velocity.
- Towards this, three dimensional CFD study of flow and temperature distribution of sodium in hot pool of FBR1&2 is carried out using ANSYS FLUENT. The computational mesh size is 1.05 million and the time taken for 1 simulation in a 16 core CPU is 3 days. For all the subsequent works, high Re k-ε model is used for modelling turbulence [5] and standard wall function with y+ > 30 is used for modelling velocity profile near wall.
- A maximum free surface velocity of 0.89 m/s is observed in the hot pool which is more than the allowable value of 0.5 m/s from gas entrainment considerations. The maximum free surface velocity decreases rapidly when the baffle width is increased from 100 mm to 500 mm and after 500 mm, the velocity remains nearly constant. So, a baffle of 500 mm width provided at 1.3 m below the free level reduced the maximum free surface velocity to 0.57 m/s. Though the free surface velocity is above 0.5 m/s, the percentage of area where velocity is above 0.5 m/s is 2.9 % only. The addition of vertical baffle also has less say in reducing the free surface velocity.



Velocity vectors (m/s) of sodium at the free surface without baffle and with baffle

PREDICTION OF FLOW & TEMPERATURE DISTRIBUTION IN THE INLET WINDOW OF IHX

- The Intermediate Heat Exchanger (IHX) connects hot pool and cold pool. The hot primary sodium which comes out of the Subassembly (SA) reaches hot pool and from there it flows through the IHX to the cold pool. Sodium from hot pool flowing in the shell side of IHX transfers heat to secondary sodium flowing inside the tubes of IHX. The temperature distribution of secondary sodium in the IHX depends on the temperature and velocity distribution of primary sodium at the inlet window. Moreover, the cross flow velocity of primary sodium faced by the tube bundle is important for the Flow Induced Vibration (FIV) studies of the IHX tubes. Prediction of velocity and temperature distribution in the inlet & outlet window of IHX is important for providing input to FIV studies of tube bundle and also to estimate the temperature variation in the outlet plenum of the IHX.
- Towards this, a three dimensional CFD study of flow and temperature distribution of sodium in hot pool is carried out to estimate the velocity distribution at the IHX inlet window. The computational mesh size is 1.05 million and the time taken for 1 simulation in a 16 core CPU is 3 days.
- The maximum resultant velocity predicted at the inlet window of IHX is 0.8 m/s. From the inlet temperature profiles, a maximum ΔT of 4 K is observed. Figures 3 and 4 show the velocity and temperature distribution over the inlet window of IHX for various circumferential positions.

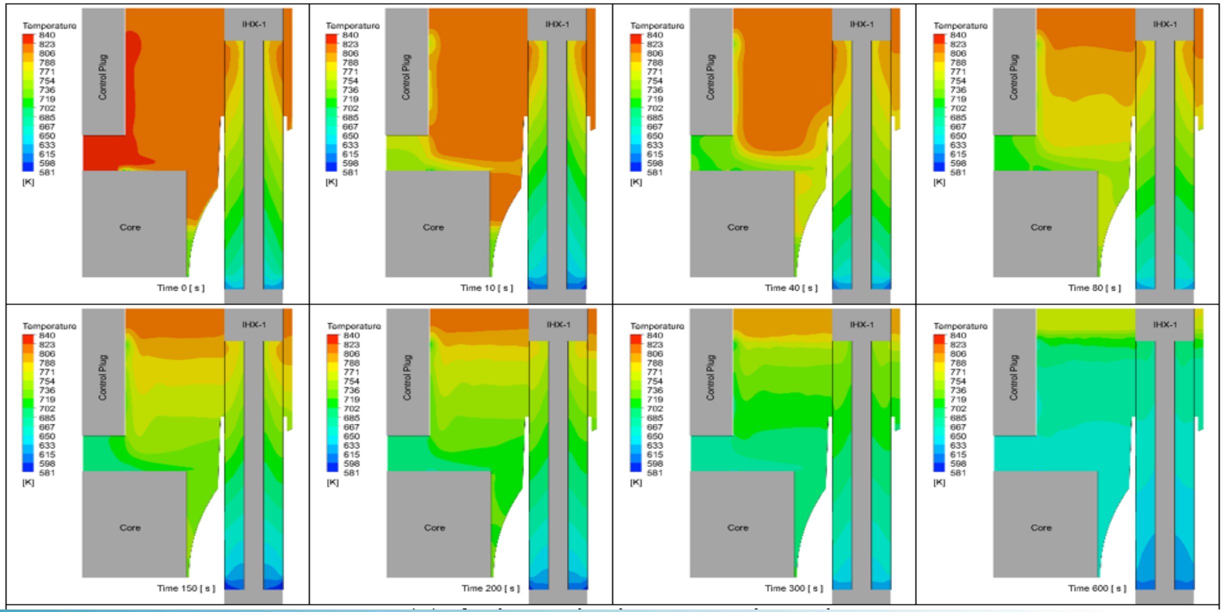


Variation of resultant velocity and temperature of sodium over the inlet window of IHX at different circumferential positions.

Results and Discussion

PREDICTION OF TRANSIENT THERMAL LOAD ON HOT POOL COMPONENTS

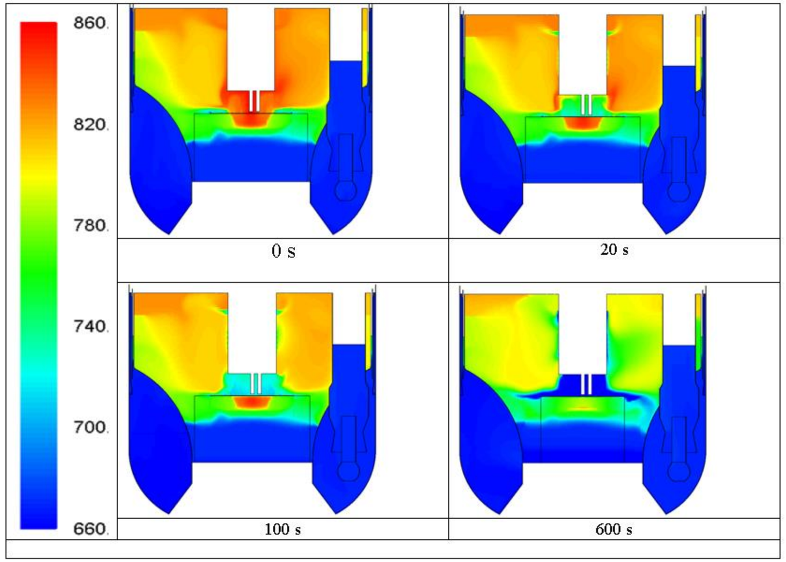
- In case reactor SCRAM, the temperature of sodium exiting the core reduces much below that present in the hot pool. Hence, there is a possibility of thermal stratification conditions to be developed in the hot pool where the cold sodium from the core tries to settle at the bottom of the pool. Thermal hydraulic effects of these phenomenon in hot pool needs to be investigated to establish transient thermal loading on various components.
- Towards this, a transient three dimensional CFD analysis has been carried out to evaluate transient temperature and velocity evolution of sodium in hot pool. Variable time step in the range of 0.001 s to 0.1 s is considered for the simulation carried out for total duration of 600 s. The computational mesh size is 1.05 million and the time taken for 1 simulation in a 30 core CPU is 15 days.
- At the CP surface, the temperature contours shows a stratification interface above holes in the shell. Stratification interfaces are also observed on the IV surface at time t=15 s which moves upwards with time. The velocity of sodium entering IHX is maximum at the bottom and a maximum velocity of 0.82 m/s is observed in the inlet window of IHX-1. At the IHX inlet window, a ΔT of 5 K is observed in the sodium stream entering it initially and the same increases to as high as 39 K during the transient.



Temperature contours (K) of sodium in the plane passing thorough IHX-1 at various instances

INTEGRATED TRANSIENT HOT POOL – COLD POOL STUDY

- During reactor transients, both IV and MV along with immersed components are subjected to rapid temperature changes, making thermal loads important for both. Towards this, transient temperature evolution of reactor pool components during reactor SCRAM is determined using an integrated fully coupled model of reactor pool. Due to the complex flow physics to be resolved, both hot and cold pools along with immersed components are modelled and analysed in a coupled form.
- An integrated CFD model of hot and cold pools with conjugate heat transfer model has been used to study the transient pool thermal hydraulic behaviour during reactor SCRAM. The computational mesh size is 2.6 million & time taken for 1 simulation in a 30 core CPU is 28 days. Time step of 0.01 s is considered for the simulation carried out for total duration of 600 s.
- Due to the capabilities of the present model, simultaneous evolution of flow and temperature in hot and cold pools has been analysed. Temperatures of important structural components like inner vessel and main vessel have been determined. The influence of heat transfer though inner vessel during SCRAM on flow and temperatures of hot and cold pool has been characterised. Temperatures of all important immersed components have been resolved. These results are important for future thermo-mechanical analysis of reactor assembly components.



Transient evolution of temperatures on symmetry plane.