EXPERIMENTAL DEMONSTRATION AND PERFORMANCE EVALUATION OF PASSIVE DECAY HEAT REMOVAL SYSTEM OF PFBR

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INTRODUCTION: Prototype Fast Breeder Reactor (PFBR) being constructed in India is a pool type sodium fast reactor. It is provided with a dedicated Safety Grade Decay Heat Removal (SGDHR) system, which works totally on natural circulation. The SGDHR system consists of four independent loops. To demonstrate and study the thermal hydraulic behavior of a loop of SGDHR system of PFBR, SADHANA experimental facility which is a 1:22 scaled down in power with Richardson number (Ri) similitude was designed. Experiments were conducted in the test facility to demonstrate the SGDHR system for all design basis events and chracterisation and performance evaluation of the system have been done.

1. OVERVIEW

Indian sodium cooled Prototype Fast Breeder Reactor (PFBR) is provided with two diverse decay heat removal systems named Operation Grade Decay Heat Removal (OGDHR) system and Safety Grade Decay Heat Removal (SGDHR) system [1, 2]. In OGDHR system, the decay heat is transferred to atmosphere through normal heat transport path systems of reactor with dedicated air cooled condensers attached with steam water system. Electric power is required to operate the OGDHR system. SGDHR system is a dedicated passive decay heat removal system. The SGDHR system consists for independent loops. Each loop consists of one sodium to sodium heat exchanger (DHX) immersed in the hot pool of PFBR, one sodium to air heat exchanger (AHX) positioned at elevated height from the DHX, associated piping and auxiliary components. One chimney per loop is provided to generate the required air flow across AHX tube bundle by natural draft. In SGDHR system, the decay heat from the radioactive primary hot pool of reactor is transferred through DHX to intermediate circuit connecting DHX and AHX, and released to atmosphere through AHX. The hot liquid sodium column of piping from DHX outlet to AHX is called hot leg. The cold liquid sodium column of piping from AHX outlet to DHX is called cold leg. Due to to net boyancy force due to temperature difference between these two legs, the sodium flow in the intermediate circuit is generated. Similarly, the required air flow is generated in the chimney due to buoyancy. Thus the operation of SGDHR system is a completely passive. Air dampers with two louvers are provided upstream and downstream of AHX which are opened on demand by powered actuators. The schematic diagram of SGDHR loop is shown in figure.1 To achieve required reliability of the system, two design concepts were adopted in the design of DHX and AHX named type A design and type B design. During normal operation of reactor, the SGDHR system is in poised condition by keeping the air dampers in closed condition. To maintain a detectable sodium flow in the intermediate loop with minimal heat loss during poised condition, louvers of the damper will be kept in crack open to allow small amount of air flow across AHX tube bundles. After reactor SCRAM, the dampers of SGDHR system are actuated to open immediately. Delay in opening of air damper by 30minutes is considered for manual intervention in case of failure in opening of air damper by remote operation. If the availability of OGDHR system is ensured, the SGDHR system is brought back to poised state by closing dampers, else SGDHR system continues to remove the decay heat. The heat removal capacity of the SGDHR system depends on the temperature of hot pool sodium where DHX is immersed, the temperature of atmospheric air which is ultimate heat sink and percentage of damper opening which determines the air flow rate.

During various design basis transients of reactor, the temperature of hot pool sodium changes significantly. Due to this variation of the temperature of hot pool sodium, the heat removal capacity of the system and flow stability of intermediate loop can be affected. The effects of the enveloping design basis events on the SGHDR circuit were experimentally studied in an experimental facility called SADHANA facility.

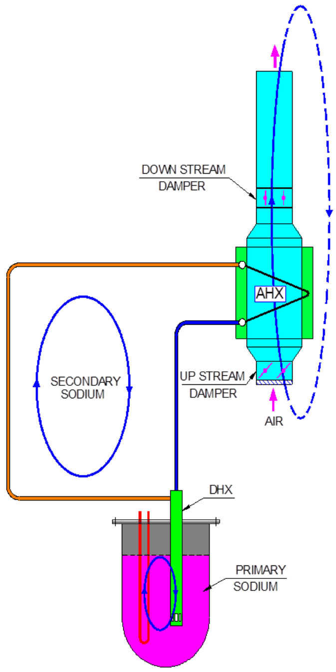

FIG. 1. Schematic of SGDHR loop

2. DESCRIPTION OF EXPERIMENTAL FACILITY [3]

To demonstrate and study the thermal hydraulic behavior of SGDHR system of PFBR, SADHANA experimental facility which is a 1:22 scaled down in power with Richardson number (Ri) similitude was designed. The flow sheet of the SADHANA facility is as shown in figure 1. The temperature parameters were maintained same. The elevation difference between the thermal centers of the secondary sodium system of SADHANA is half of the prototype. A test vessel was designed to simulate the hot pool of the rector. The vessel houses the model DHX, immersion sodium electrical heaters, thermocouples and sodium level probes. DHX and AHX in SADHANA were similar to that of SGDHR of PFBR. DHX, AHX and chimney were designed to corresponding of 1/22th heat removal capacity. Buoyancy driven sodium flow through the intermediate loop of SADHANA and air flow through chimney were measured by a permanent magnet flow meter and hot wire anemometer respectively. The temperatures of sodium and air were measured by using thermocouples.

3. EXPERIMENTAL RESULTS

The experiments conducted were largly ctaegorised as steady state experiments for performance evaulation for conditions like nomonal operating conditions, various primary pool temperature, paritail opening of air damper, main vessel leak event and unfavourable direction of sodium flow in intermediate circuit; transient experiments like reposnse against damper opening, spurious SCRAM where maximum cooling rate of sodium in primary sodium pool and extended Station Black Out (SBO) where maximum heating rate in primary sodium pool.

3.1. DEMONSTRATION OF SGDHR SYSTEM AT NOMINAL OPERATING CONDITION

The nominal operating condition of the reactor during shut down was simulated in the test vessel and the air dampers were kept open. The operation of SADHANA loop was stable without any fluctuations in temperature or sodium flow during the steady state condition. At 550°C sodium pool temperature, the heat removal capcity and sodium flow rate in the intermediate loop are respectively 24.8% and 9.7% more than its nominal values. Further experiments were conducted for various pool temperature also and results are shown in figure 2. From the experiments, the design philosophy, design methodology were validated.

3.2. DEMONSTRATION OF SGDHR SYSTEM DURING MAIN VESSEL LEAK EVENT

The inlet of shell side of DHX is perforated such that the availability of DHX is ensured during main vessel leak event. During this design basis event, only 10% of sodium entry area and 55% of effective heat transfer area are available. From the experiments, it was demonsrated that the heat removal capacity is only affected by 5%. The heat removal capacity of system for various primary sodium level with respect to the DHX tube length is shown in figure 3.

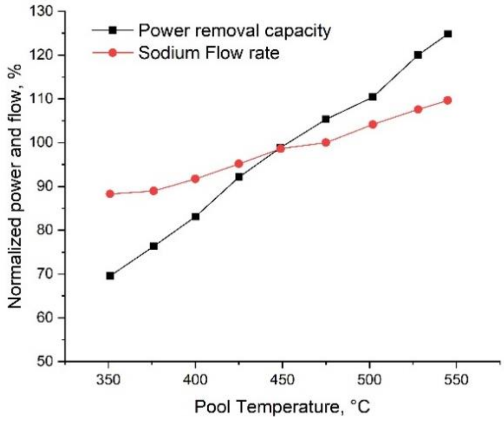

FIG. 2. Heat removal capacity with respect to pool temperature

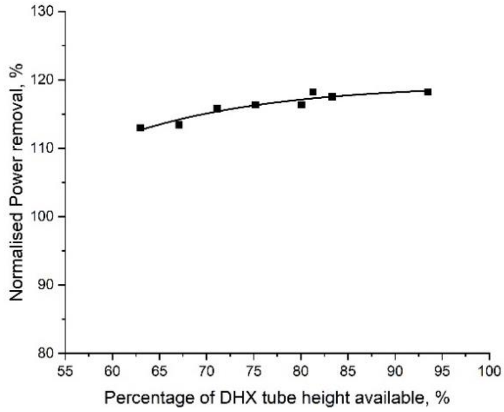

FIG. 3. Heat removal capacity with respect to level drop

3.3. PERFORMANCE OF SGDHR SYSTEM DURING UNFAVOURABLE CONDITION

The unfavorable (reversed flow) direction in intermediate sodium side of SGDHR system, which affect the performance of AHX and DHX were simulated in SADHANA facility. In this condition, heat exchangers perform as parrlell heat exchangers where in normal condition heat exchnagers are as counterflow heat exchanger. During reversed flow condition, the reduction in power removal capacity of system was 46.6%.

The air dampers are provided with two lowers operated by diverse actuators. In case of failure of one of lourver to open also, the reduction in power removal capacity is just 1%. This confirms the high reliability of the SGDHR systeem.

3.4. RESPONSE OF SGDHR SYSTEM DURING SPURIOUS SCRAM

Initially the air dampers were in crack open position and the system kept in poised state with sodium flow rate of 57.6% of nominal flow rate. After initiation of SCRAM scenario, the sodium flow rate in the intermediate circuit was reducing up to 17.5%, since the temperature of hot pool was reducing. It was observed that the temperature of pool was lesser than the temperatures of the intermediate circuit for about 15 minutes. Hence the intermediate circuit was losing heat through DHX to the hot pool and the temperature difference between the hot and cold legs was reduced which reduces the induced flow rate in the intermediate circuit. After 30 minutes of initiation of SCRAM scenario, the air dampers were opened. Then the temperatures of sodium in the cold leg were reduced to below the pool temperature due to the action of AHX. The temperature difference between hot leg and cold leg was increased and correspondingly the sodium flow rate was increased to the steady state value of 70.9% in 8 minutes with minimum oscillations. The response of the sodium flow and temperature in the intermediate circuit are shown in figure 4 and figure 5 respectiovely.

3.5. RESPONSE OF SGDHR SYSTEM DURING SBO

During SBO, initially the sodium flow in the intermediate circuit got reduced up to 51.4% from 57.6% of nominal flow rate as the hot pool temperature was falling and further started to increase along with pool temperature raises. The sodium flow tended to reach the stable value of 64.5%, since the pool temperature was almost stable at 570°C. After 30 minutes of initiation of SBO, the air dampers were opened. The sodium flow reached to the maximum value corresponding to the pool temperature within 7 minutes. Evolution of the sodium flow and temperatures are given in figure 6 and figure 7 respectively. The temperature of sodium in the hot pool was always higher than the temperatures of sodium in the intermediate circuit and hence no flow oscillations or flow reversal were observed.

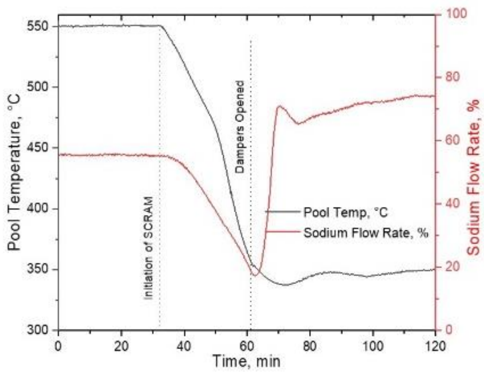

FIG.4: Sodium flow during SCRAM

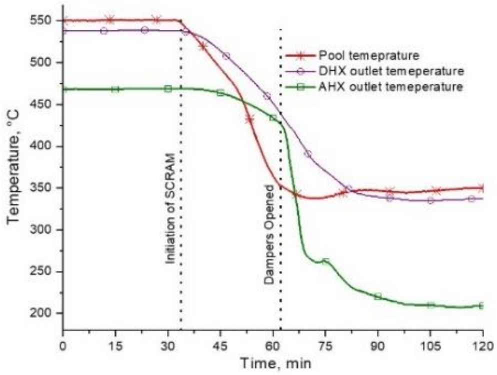

FIG.5: Temperature during SCRAM

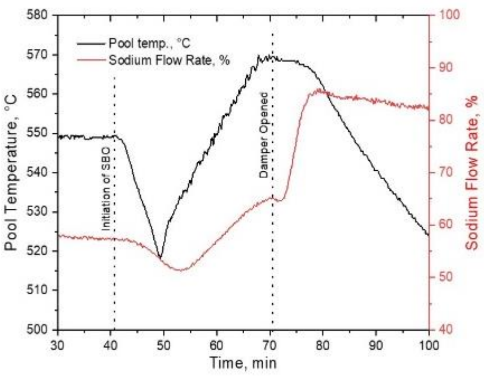

FIG.6: Sodium flow during SBO

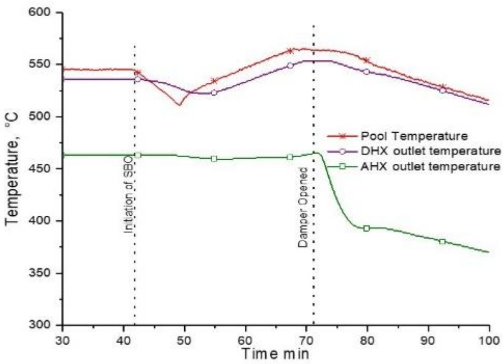

FIG.7: Temperature during SBO

4. SUMMARY

The functionality, design philosophy, design methodology, stablility of SGDHR system of PFBR were succefully demonstarated through various steady state experiments in the sclaed down model, SADHANA facility. The behavior of the SGDHR system of PFBR during various design basis plant transients were experimentally studied for events such as a spurious SCRAM and SBO, which encompass the conditions of maximum cooling and heating rates of the reactor pool, respectively. The availability and stability of the system was demonstrated for these transient cases. The direction of flow in the secondary system of the SGDHR remained unchanged during all design basis plant transients.

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