THERMAL HYDRAULIC DESIGN VALIDATION OF STEAM DRUM INTERNALS, MODERATOR AND LIQUID POISON INJECTION SYSTEMS FOR AHWR

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Abstract

Two experimental test facilities for thermal-hydraulic studies in steam drum, moderator flow and liquid poison injection system have been designed, fabricated, installed and commissioned in Engineering Hall-7, BARC, which are important for AHWR technology development. Setting up of the test facilities involved design of various components, selection of appropriate materials, elaborate mock up tests, fabrication of components, installation of instruments and their controls. Measures were taken to ensure safety of the experimental set-up and the personnel working on the setups. The task was highly complicated and challenging because of fabrication of large number of components, requirements of flow visualization of single-phase and two-phase flow and hundred percent leak proof joints with various nozzles. The scaling of the facilities has been done by simulating various non-dimensional numbers. The heat generation in the moderator has been simulated by electrically heated calandria tubes. Experiments were performed in these facilities. This paper deals with the work performed and results obtained in brief.

Introduction

The design of Advanced Heavy Water Reactor (AHWR) is in progress in BARC. The steam-water separation is achieved in AHWR steam drum naturally without the use of a mechanical separator. This necessitated the use of gravity separation in the steam drum. Liquid-vapour separation without aid of a mechanical device may not be fully effective and may lead to two undesirable phenomena, namely, carryover and carryunder. The adequacy of the gravity separation phenomenon in the steam drum needs to be ensured. Two in-house developed computer codes, GSEP-CO and GSEP-CU, to predict the carryover and carryunder require experimental data for their validation. A multichannel Air Water Loop (AWL) was designed, fabricated and installed to experimentally investigate the phenomena such as carryover and carryunder relevant to AHWR steam drum.

In AHWR, heavy water moderator is used to thermalize the neutrons inside the calandria. Calandria is a vertical cylindrical vessel containing vertical calandria tubes. A large amount of heat is generated in moderator due to the thermalisation process. Hence, to maintain its temperature, heavy water moderator is circulated through heat exchangers. In the calandria, the flow is mainly affected by momentum of inlet jets and buoyancy due to heat generation. The design and location of the inlet and outlet nozzles should be such that the maximum moderator temperature and impact velocity on the calandria tube bank are within limit.

Shut down system-2 (SDS-2) of AHWR is a fast acting system in which liquid poison is injected in the calandria vessel. This system is designed to shut down the reactor in a very short span. A Moderator and Liquid Poison Injection Test Facility (MLPITF) was designed, fabricated and installed to investigate the duration and get proper
distribution of poison in the moderator. To optimize calandria configuration for moderator flow distribution, experiments are being conducted in a scaled model. Further, experiments are carried out to optimize performance of shut down system -2. For this purpose a Moderator and Liquid Poison Injection Test facility was designed, fabricated and installed to investigate the duration and dispersion of poison in the moderator.

Brief overview of facilities

Two experimental test facilities named, Air Water Loop (AWL) and Moderator and Liquid Poison Injection Test Facility (MLPITF) have been designed, fabricated, installed and commissioned in Engineering Hall-7, BARC. The details of the facilities are described below.

Air Water Loop (AWL)

AWL has been designed and installed to study carry out thermal hydraulics experiments relevant to AHWR steam drum. The major objectives include investigation of the carry-over and carry-under phenomena in steam drum of AHWR, measurement of swell in the steam drum (pool void fraction) and testing performance of steam drum internals. The AWL consists of a semi-circular air-water drum simulating scale down AHWR steam drum with internals, rectangular water tank, piping simulating the risers and downcomer (Fig. 1). The air injection lines to simulate the two-phase flow at drum inlet, air-separator to separate the air at drum exit were also designed and fabricated.

The steam drum is 1/8th slice of the prototype, with 15 tail pipes (62.7 mm ID) and one downcomer (134.5 mm ID). Superficial velocities of individual phases in the prototype and model are same. One end of these tail pipes and downcomer is connected to the air-water drum as in the prototype while other end is connected...
to a storage tank. Air is injected at the bottom end of the vertical tail pipes. The loop flow is generated due to the density difference between two-phase air-water mixture in the tail pipe and single-phase water coming from water tank via downcomer. The two-phase flow of air-water mixture then enters in the air-water drum and air gets separated by gravity. The separated water flows towards water tank via downcomer. Some of the photographs of the installed facility are shown in Fig. 2.

The different parameters to be measured are swell level, pool void fraction and entrainment in air-water drum, pressure drop in tail pipe and downcomer. The swell in the air-water drum is measured by change in measured levels. Flow measurement in the single-phase horizontal pipe is carried out by calibrated pipe taps (pipe flow meter). Pressure drop and level is measured with differential pressure transducers or transmitters. Bubble and droplet size distributions are measured using high speed photography. Special provisions are built in the facility to measure the entrainment and pool void fraction.

**Experimental work in Air Water Loop (AWL)**

Steady state experiments on two-phase natural circulation were carried out with different initial water inventory and varying the air injection flow rates simulating the AHWR conditions (Fig. 3). Steady state circulation flow rates, pressure drop in single and two-phase regions of the facility were measured and are validated using in-house developed code. Also a scenario similar to on-load refueling was experimentally simulated in AWL. Initially all the channels are subjected to same air injection flow rate. Air injection flow is reduced to zero in one of the channel. The channel acts as downcomer and reverse flow is observed. With initiation of air injection in that channel flow is still observed to remain in reverse direction. Only upon further increasing the air injection flow rate, flow becomes forward. Such hysteresis effect was found to be dependent on the rate of change of air injection flow rate. Fig. 4 shows the flow reversal phenomenon observed experimentally. Figs. 5a and 5b show some of the photographs taken for flow visualization during experiments.
Moderator and Liquid Poison Injection Test Facility (MLPITF)

A semitransparent scaled experimental setup of AHWR calandria was designed, fabricated and installed for moderator flow distribution studies. The model has been designed in such a way that Archimedes number is same as prototype. The model consists of calandria shell with calandria tubes, inlet-outlet nozzles, etc. The acrylic flanges and acrylic windows in the calandria shell are provided for visualization purpose. In the model, heat generation is simulated by direct electrical heating of calandria tubes. The calandria tubes are connected to the electrical supply through motorized auto transformers. Local electrical control panel is provided to operate the power supply system. The current, voltage and power are measured. Various instruments like magnetic flow meters, thermocouples, rotameters, pressure gauge, level indicator and level transmitter were installed in the test setup for measurement purpose. Spatial temperature distribution was measured using large number of thermocouples. Spatial velocity distribution is measured by using pitot tube. The data obtained are being utilized for computational fluid dynamics code validation. The test facility has been hooked up to a PLC based SCADA System. The instrument signals from field are terminated to PLC remote I/O modules in a local instrumentation control panel. For safety purpose, software and hard wired trips are provided based on high temperature signals. Earthing was provided on calandria shell, transformers and armour of cable for personal safety. Fig. 6 shows the photographs of some of the components of MLPITF. To carry out experiments on liquid poison injection and its distribution inside the calandria, the components of SDS-2 are installed and commissioned. The model consists of a gas tank for pressurization of poison, poison tanks and injection tubes for injecting the poison into the moderator. Liquid Poison is injected in scaled calandria through perforated headers. Eight poison segmental circumferential injection headers are provided at the middle of calandria. Each header has nozzles for injecting poison into the moderator. On the bottom tube sheet, perforated injection headers are also provided. Poison and gas tank are connected with these injection headers. A gas tank for pressurizing poison tank was connected through a quick opening solenoid valve. Pressure gauge, pressure transmitter, relief valve, nitrogen supply line, level gauge and level transmitter were provided. Facility is hooked up to a PLC based SCADA System. Experiments are conducted at different injection pressures. Some of the photographs of the installed facility are shown in Fig. 6.
Experimental work in Moderator and Liquid Poison Injection Test Facility (MLPITF)

The experimental studies on moderator flow distribution have been carried in the test facility. Experiments were also performed on the liquid poison injection system for different cover gas pressures. Moderator flow and temperature distribution were complimented by detailed three dimensional CFD simulations. CFD simulations were performed using PHOENICS CFD code. The poison distribution inside calandria was also computed. Further, a computer code, COPJET is developed which simulates gas expansion, system piping, perforated injection headers and poison progression into the calandria. The code results have been compared with the data available in the literature and with the PHWR data (Figs. 7 & 8).

Conclusions

Two experimental test facilities (AWL & MLPITF) for thermal-hydraulic studies in steam drum, moderator flow and liquid poison injection system have been designed, fabricated, installed and commissioned. Steady state experiments on two-phase natural circulation were carried in AWL. Measured steady state circulation flow rates, pressure drop in single and two-phase regions of the facility have been validated using in-house computer code. Flow reversal phenomenon was experimentally studied and hysteresis effect was found to be dependent on the rate of change of air injection flow rate.

The experimental studies on moderator flow and temperature distribution were carried out. The results were simulated using a CFD code. A computer code, COPJET was developed which simulates gas expansion, system piping, perforated injection headers and poison progression into the calandria. The code results have been compared with the experimental data and data available in the literature.