Chapter 1 Introduction

Various industries deal with several two-phase flow applications with large stratified flow reservoir. Therefore, various researchers carry out experimental as well as theoretical studies across the world. Loss-Of-Coolant Accidents (LOCA) occurring in Pressurized Heavy Water Reactors (PHWRs) is one of the applications. During such LOCA, the heavy water, which transport heat from the nuclear reactor core, is lost through the break in the pipe. This result in risk of the overheating of the nuclear reactor core and can trip the reactor or can cause damage, or perhaps can melt down the reactor core.

According to report of IAEA (2003), LOCA's are classified into two categories, based on the area of the break relative to the area of the largest cooling pipes. If an area of the break is more than twice the area of the largest cooling pipes, LOCA is known as Large Break LOCA (LBLOCA). If the area of the break is less than twice the area of the largest cooling pipes, LOCA is known as Small-Break LOCA (SBLOCA). SBLOCA may occur because of spurious opening of liquid relief valve and/or break in various locations such as, in inlet reactor header, outlet reactor header, pump suction line, and other locations such as on pressuriser connecting pipe lines, feeder pipe lines connected to the header.

In SBLOCA, jets of heavy water or heavy water-steam mixture come out of the breaks and cause a decrease in pressure in the cooling water circuit. It leads to boiling of the heavy water, resulting in steam formation. The separated steam is accumulated in the header of the PHWR, which is situated in the upper part of the nuclear reactor system. If no heavy water was supplied by the emergency core cooling system in the inlet header to make-up the liquid discharged from the break, a distinct layer of steam and heavy water interface is created in the header. This is known as the stratified condition of inlet header. Hence, two-phase flow would be discharged through the header depending upon the height of the interface between heavy water and the steam. Thus, water level in the reactor core would continue to drop causing the reduced flow of coolant supplied to the reactor core. The deficiency of coolant may lead to the overheating of the reactor core and may damage the sheath of nuclear fuel rods placed in the nuclear reactor core. Because of the damaged sheath of the bulk of fuel rods, more fuel would be exposed to nuclear reaction may be resulting in rapid increased nuclear reaction leading to high generation of power by nuclear reactor and eventually nuclear reactor would be tripped by the normal Reactor Regulating System (RRS). If the normal RRS is inactive or damaged or rate of increase of power in the reactor is rapid and beyond its control, then this situation may put the reactor in uncontrolled situation leading to melt down of the reactor core. Table 1.1 gives the list of LOCAs occurred in nuclear reactors across the world.

Table 1.1 : List of LOCAs in Nuclear power stations

(Courtesy by: https://en.wikipedia.org)

Year	Location	Effect
1978	Pinawa, Canada	Heavy leakage of coolant.
1979	Middletown, USA	Partial core meltdown.
1983	Pickering, Canada	Pressure tube, that holds the fuel bundles, ruptured.
1986	Bruce, Canada	Pressure tube, that holds the fuel bundles, ruptured.
1994	Pickering, Canada	Heavy leakage of coolant.
2011	Fukushima, Japan	Meltdown of three nuclear reactors.

A typical horizontal header of PHWR consists of a large horizontal pipe closed on both sides with the flow entering from a number of vertical openings called turrets, located at the top of the pipe, and exiting through banks of feeders at various axial locations along the header length. Small diameter pipes called feeders or branches or breaks individually connect the fuel channels in each core pass. Usually, a bank of feeders consists of five feeders at a particular axial location of the header that lead cooling fluid to the core. A bank of five feeders as shown in Figure 1.1, at a particular cross section of the header consists of two feeders mounted horizontally at 0^0 and 180^0, two inclined feeders mounted at 45^0 and 135^0, and one feeder mounted vertically downward at 90^0. During postulated LOCA accident scenario, flow stratification in reactor header starts the gas admission in various feeders attached to it, therefore, the feeder supplies gas, and liquid mixture in varying proportion. Thus, detail understanding of gas entrainment is essential in case of PHWR as this phenomena result in inadequate cooling of the reactor core.

Zuber (1980) reported a distinct phenomenon namely vapor-pull through in case of a branch mounted on top, bottom, or side of the pipe during a single discharge from a large pipe under stratified condition. If the branch is located below the interface, at a certain level of interface, vapor may be entrained by a vortex or vortex-free motion, into predominantly liquid flows through the branch. This phenomenon is called as gas entrainment or vapor pull through.

Figure 1.2 shows of vapor pull through in the side branch. Thus, a branch located below the interface level in stratified phase flow condition, a mixture of gas and liquid, rather than single phase of liquid may be discharged through the branch. To predict the Onset of Gas Entrainment (OGE) phenomena, he proposed simplified

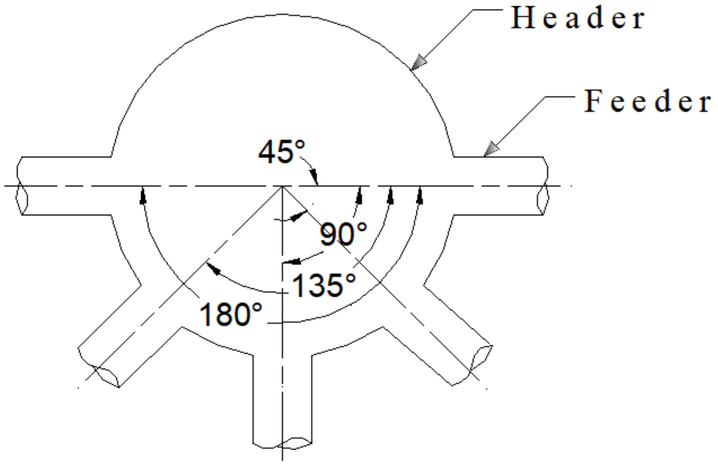

Figure 1.1: PHWR header cross section

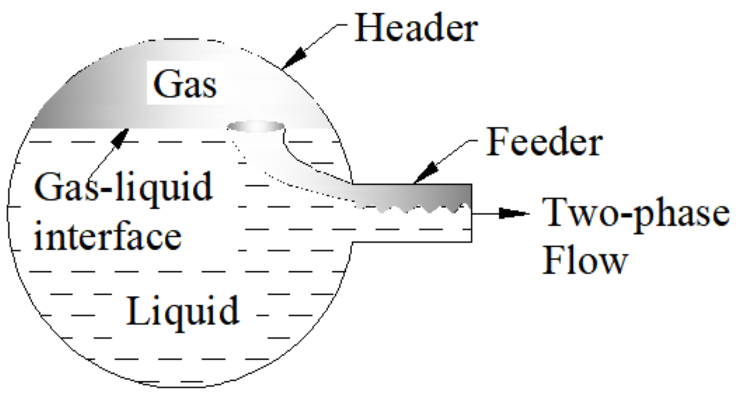

Figure 1.2 : Example of vapour pull through

correlation combining relevant system parameters and branch dimension. Later, several detailed theoretical and experimental investigations were reported to understand the OGE phenomena under stratified flow condition employing different sizes of the branches in case of single and dual discharges. The single discharge investigations were reported for side, inclined, and bottom branches mounted on the vertical flat surface or circular surface, whereas dual discharge investigations were reported only for vertical flat surface with centre line of the two branches falling on vertical plane or horizontal plane. Thus, when multiple branches mounted on both the sides of circular surface, no information is available in the open literature for determining the onset of gas entrainment.

This deficiency of information for critical height at OGE may be addressed by conducting experimental investigation with a wider range of data and with different branch combinations of multiple discharges.

Therefore, the motivation for the present research study is to provide the first-hand detailed information about the critical height or the incipient height of liquid for OGE for the single discharge and multiple discharges in case of the branches mounted on circular surface with centrelines falling on a common vertical plane by carrying out experiments. This study would provide a realistic understanding of OGE in PHWR header during multiple branches mounted on circular surface and effect of discharge from one branch over the discharges from the other branches.

Thus, to meet the objective, experimental test facility was designed and fabricated at The Maharaja Sayajirao University of Baroda for providing realistic information of OGE during multiple branches mounted on circular surface with stratified flow conditions. The test facility includes a circular test piece mounted with five branches on the common vertical plane, was placed inside the test chamber. One end of the test chamber was attached to manual regulating unit to control the supply of water and air in the test chamber. Viewing windows were provided in the test chamber to visualize as well as to capture the video of the flow phenomena. The two-phase flow created in the test chamber at certain liquid height was properly directed with the help of two-phase flow pipelines to the phase separators, where the air and water component was separated completely. To provide same flow conditions for every two-phase flow line, Froude number was kept same by operating the throttle-valve inserted in each of the two-phase flow pipes. The water and air quantity were removed with the help of two discharge pipes attached at downstream of the phase separator. These discharge pipes used to keep the steady liquid height and air pressure in the phase separator during removal of water and air. Under this steady condition, the quantity water entering the phase separator was same as the quantity of water discharged from the phase separator. The pipe for discharging water was provided with high accuracy flow meter to measure the water component removed from the phase separator. The critical height or incipient height of the liquid during the OGE was found by using the glass tube liquid indicator.

The objective of the present study is met by taking the following steps:

1. To visualize the onset of gas entrainment that may occur during single and multiple discharges. The experimental setup was designed and fabricated to facilitate this investigation.
2. To generate experimental data for determining the incipient height at OGE for different Froude number from a large stratified region through small branches mounted on circular surface. A test piece of 1/5th scale for PHWR header-

feeder configuration was designed and fabricated with the branches mounted on circular surface with centrelines falling in the common vertical plane. The test matrix was designed to include data of single discharge, dual discharge, triple discharge, quadruple discharge, and quintuple discharge condition.

3. To develop correlation for determining the critical height at OGE during single and multiple discharges from a large stratified reservoir through small branches mounted on circular surface. In future, this correlation may help to model similar OGE phenomena that may occur during single, and multiple discharges.