NUCL 355 - Nuclear Thermal-Hydraulics Laboratory

Experiment 8: Two-Phase Natural Circulation

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- **Objectives**

1. Demonstrate a two phase natural circulation in a loop
2. Obtain a curve of the flow in the loop vs. the void fraction in the riser

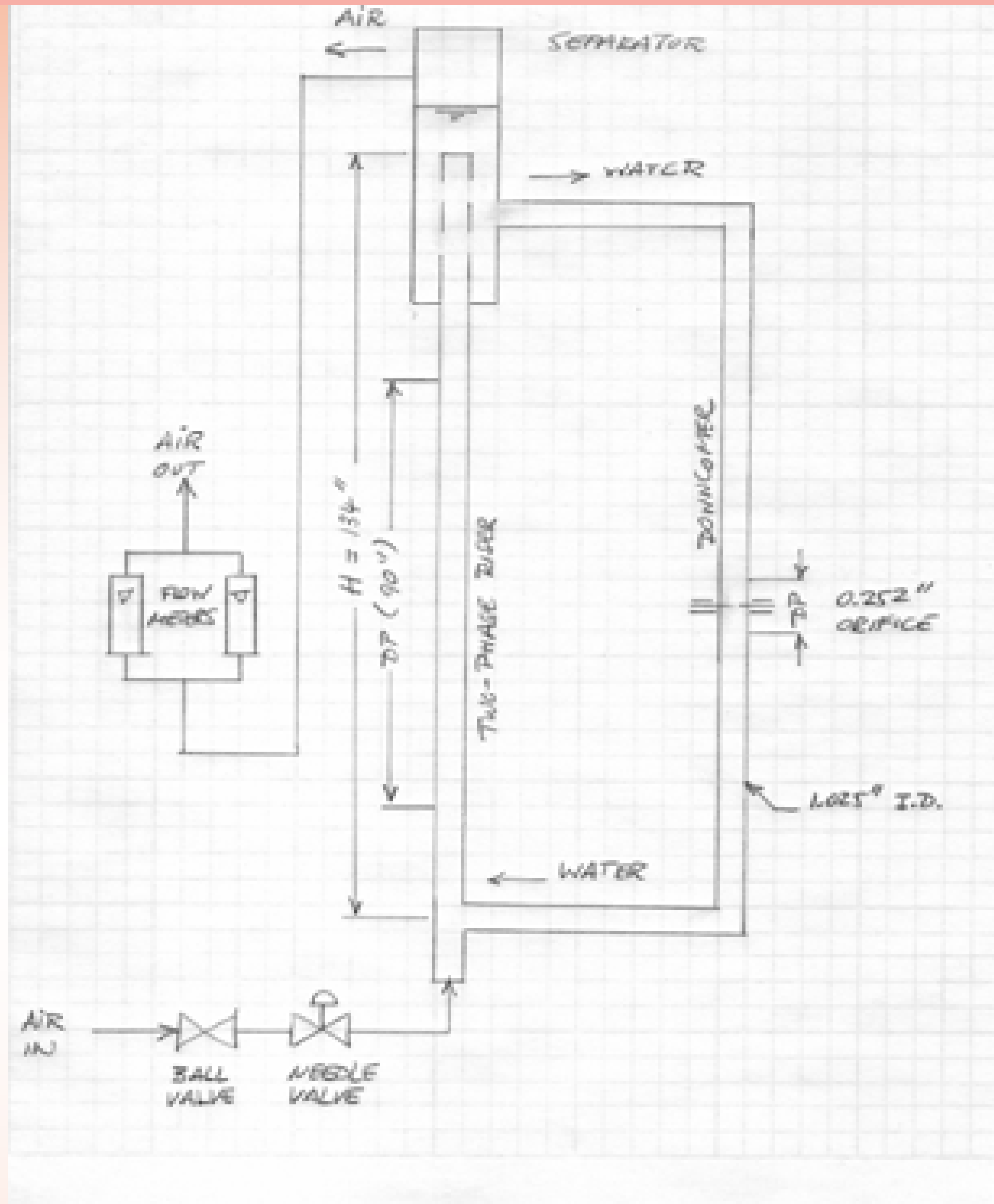
Experimental Apparatus

The two phase natural convection loop consists

- a compressed air inlet at the bottom and a separator at the top.
- Flow is induced by the pressure difference between the two-phase riser and the single-phase downcomer.
- The downcomer has an inside diameter of 1.025 in.
- The orifice plate in the downcomer is 0.252 in. diameter.

The test facility for two-phase natural circulation

1. flow loop
2. air separator
3. orifice
4. rotameters
5. DP cell
6. valves



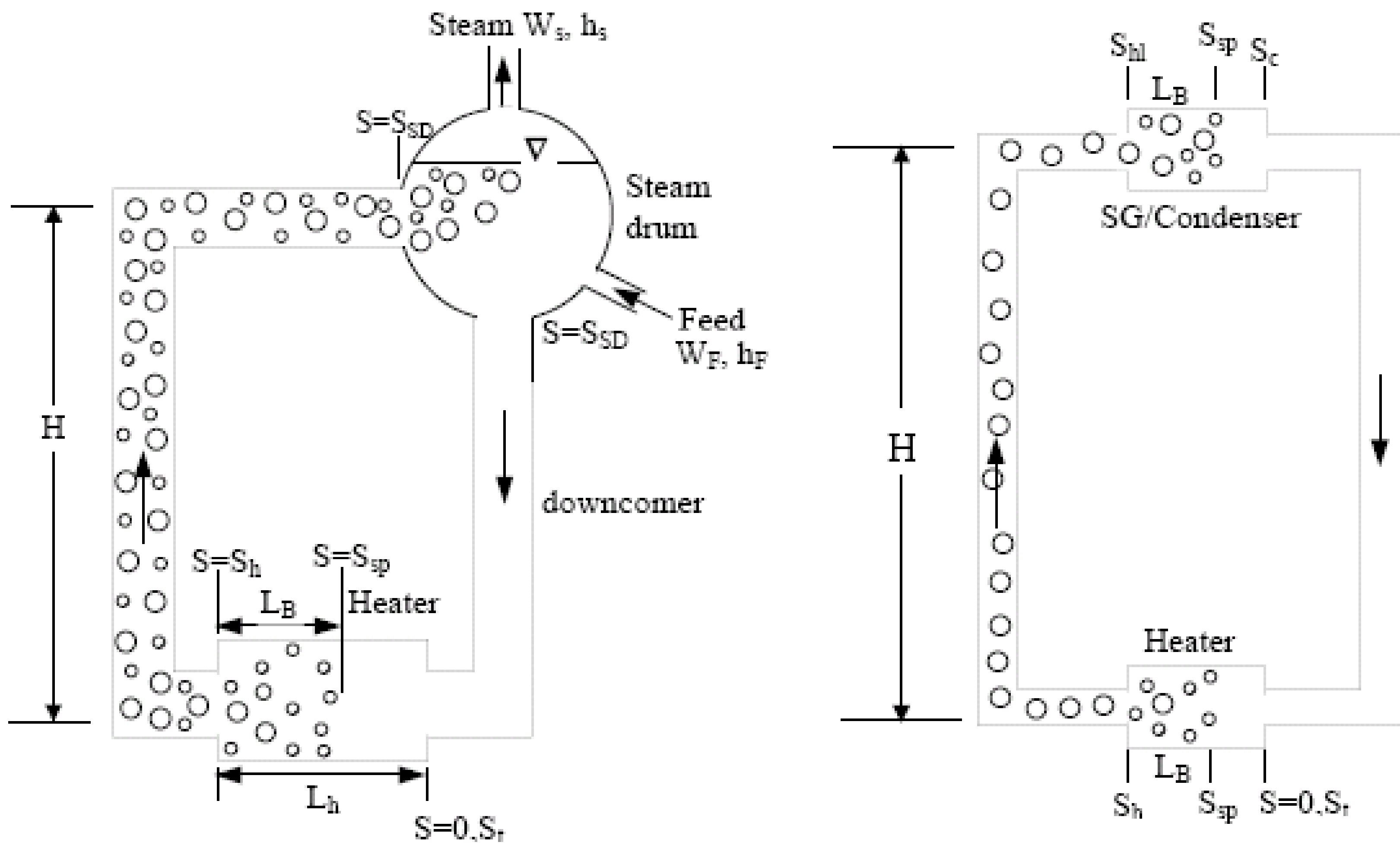
Experiment Procedure:

- Read the pressure ranges of the two DP cells and write them down in your lab book. The corresponding output ranges are 1-5 Volts.
- Make sure the valve in the low flow air flow meter is fully open and the other one is closed.
- Make sure the inlet needle valve is slightly open.
- Open the inlet ball valve.
- Set the air flow rate with the needle valve to the following values: 2, 5, 10, 15, 20, 30 SCFH and 1 SCFM.
- Sketch the flow regime in the riser at each flow.
- Measure the voltage output of the 2 DP cells at each flow. Take 10 readings at each flow and average them to obtain time-averaged pressure drops.

Data Analysis

For each air flow rate calculate and tabulate:

1. The pressure drop across the riser and the orifice plate.
2. The standard error of the pressure drops.
3. Calculate the mass flow rate across the orifice plate. Write down one sample calculation.
4. Do an error propagation analysis to calculate the error of the flow rate. Include one sample calculation.
5. Calculate the void fraction in the riser and associated error.



(a) Loop relevant to BWRs

(b) Loop relevant to PWRs

Fig.1: Two-phase NCLs relevant to nuclear reactors

Natural Circulation

1. Both single-phase and two-phase natural circulation systems are important for nuclear industry.
2. Single-phase NC is used for decay heat removal in PWRs, VVERs and PHWRs
3. Two-phase systems - Natural Circulation Boiling Water Reactors (NCBWRs) -ESBWR, VK-300 and AHWR, Natural Circulation Steam Generators (NCSG) in PWRs & PHWRs and thermo-syphon reboilers in chemical process
4. The primary function of a natural circulation loop is to transport heat from a source to a sink.
5. The heat transport capability of natural circulation loops is directly proportional to the flow rate it can generate.

NC Governing Equations

- The water density difference between the cold leg and the hot leg establishes a pressure difference between the IC supply line and the IC drain line. This pressure difference drives the natural circulation flow in the IC line. The pressure difference is calculated as

$$\Delta p = g l_h (\rho_c - \rho_h)$$

- Momentum equation

$$\rho_r \frac{dV_r}{dt} \sum \left(\frac{A_r}{A_i} \right) l_i = -\frac{1}{2} \rho_r V_r^{\,2} \sum_i \left(\frac{f_i l_i}{D_i} + K_i \right) \left(\frac{A_r}{A_i} \right)^2 + (\rho_c - \rho_h) g l_h$$

$$\rho_r V_r^{\,2} \sum_i \left(\frac{f_i l_i}{D_i} + K_i \right) = (\rho_c - \rho_h) g l_h$$

NC Governing Equations

If the void fraction in the hot leg is α, then the density in the hot leg is

$$\rho_h = (1-\alpha)\,\rho_l + \alpha\,\rho_g$$

cold leg

$$\rho_c = \rho_l$$

Momentum equation

$$\rho_r V_r^{\,2} \sum_i \left(\frac{f_i l_i}{D_i} + K_i \right) = (\rho_c - \rho_h)\, g l_h$$

The void fraction is obtained as

$$\alpha = \frac{\Delta p_{two-phase}}{(\rho_l - \rho_c)\, gL}$$