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EVAPORATION IN THIN WATER FILM UNDER REDUCED PRESSURE CONDITIONS: HEAT AND MASS TRANSFER CHARACTERISTICS

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1. ABSTRACT

The leakage in the nuclear reactor containment due to fracture/thermal stratification can cause the leakage of high-pressure fluid into the low-pressure environment. This results in the high pressure drop and phase change from liquid to vapour. This physical phenomenon is called flash evaporation; to avoid any accidental mishap, it is important to study it. This work investigates the thermodynamic phenomena of liquid film flash evaporation through an experimental inquiry. Results suggested that significant water vaporization occurs during the initial stage of the flashing, which results in a large temperature drop. The large superheat value makes the process more violent and increases the flashing intensity.

2. INTRODUCTION

The flash evaporation or flashing process is where liquid rapidly vaporises under atmospheric pressure conditions and lowers the saturation pressure corresponding to the liquid temperature[1],[2]. Since the last century, liquid flash evaporation has found widespread applications in industries, including flash power generation, spray cooling technology, desalination market, and more [3]. Miyatake et al.[4] performed experiments on pure water flash evaporation within a tank. The water height ranged from 100 to 225 mm, the initial temperature ranged from 40 to 80 °C, and degree of superheat between 2.5 and 5.5 K. They proposed utilizing the non-equilibrium fraction (NEF), which evaluates the completion of flash process. Saury et al. [5] experimentally explored the water film flashing, having degree superheats varies from 1 to 35 °C and initial temperatures from 30 to 75 °C. They proposed a proportional relationship between the mass of liquid evaporated by flash evaporation and the superheat derived from heat and mass balance in the chamber. Singh et al. [6] analysed the impact of initial pressure and temperature on the flash process of pure water. The findings suggested that at higher initial temperatures and lower initial pressures, the equilibrium temperature obtained could be lower, and the temperature drop was faster.

The impact of experimental parameters has also been studied to optimize the cooling and vaporization performance of static flashing.The research findings will be helpful in improving the efficiency of desalination and cooling systems and further provide optimum parameter values for the safe operation of high vacuum types of equipment and the prevention of accidents

3. METHDOLOGY

The mass vaporized during the flashing can be obtained through energy or mass balance. Due to the sudden pressure drop, vapour generation happens inside the flash chamber and shifts towards the vacuum tank. All the energy constituted in the superheated liquid was transformed in the form of latent heat of vaporization because of the well insulation of the flash chamber. Thus, the mass conservation equation can be written as.

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$$m_{ev} = m_o C_p \Delta T / h_{fg} \quad (1)$$

Here, m_0, m_{ev} are the separately initial liquid mass and vapour mass respectively. Cp is specific heat at constant pressure, and h_{fg} is latent heat of vaporization. Due to the well insulation and fast nature of the process, the thermal losses from the convection and radiation component are neglected.

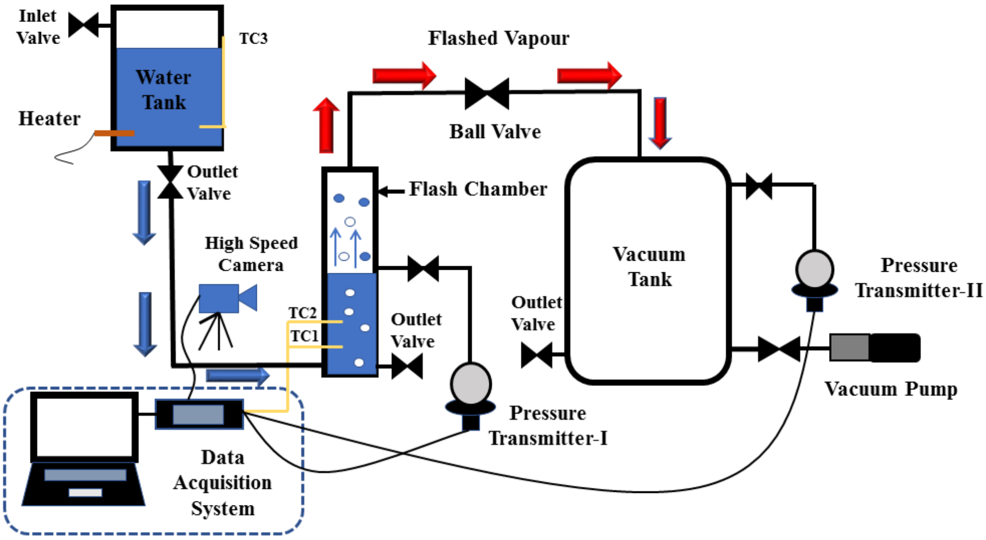


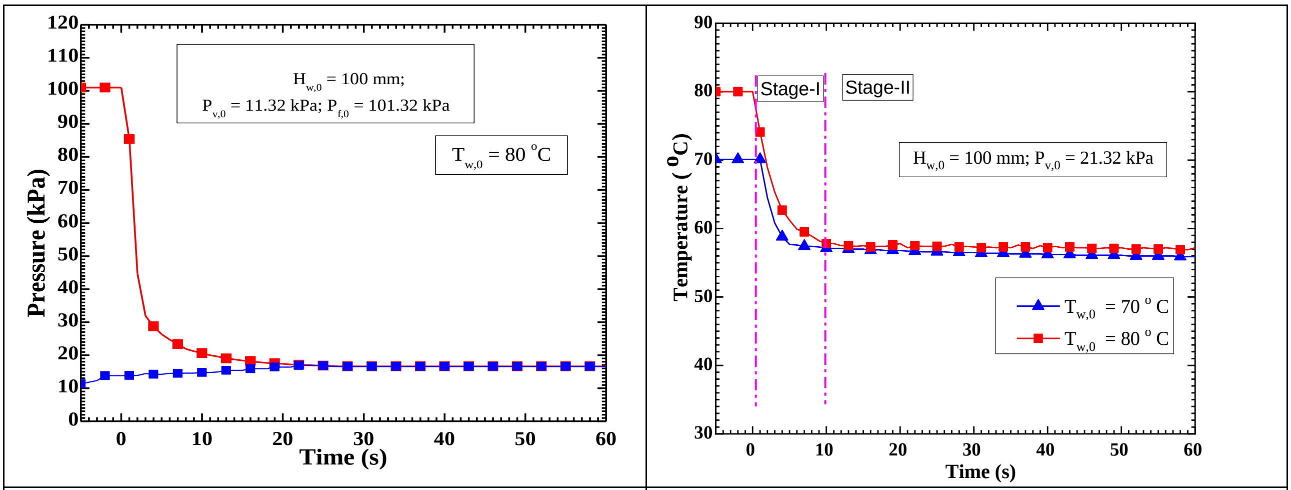
Fig. 1. Schematic diagram of the experimental system.

3.1 EXPERIMENTAL APPARATUS AND PROCEDURE

The experimental loop system is illustrated in Fig. 1. As part of the experiments, a normal water film is flashed between 65 and 80 °C at an initial liquid film height of 100 mm and a vacuum tank pressure range of 11.32 kPa to 41.32 kPa. The experimental setup comprises an acrylic transparent tube a diameter of 5 cm and 48.5 cm in height. A hand-operated brass valve 3 m pipe connects the vaporization chamber to a 500 L sealed surge tank. One heating element of 3 kW capacity is installed in the water tank to heat the incoming water into the vaporization chamber up to the required temperature. The temperature change of the liquid and vapour is measured by thermocouples placed within the chamber. An analogue pressure gauge and electronic transmitter are installed on the vaporization chamber and vacuum tank to assess pressure alteration. The relative uncertainty found in the temperature, pressure and mass measurements is 0.51%, 0.12% and 0.1 %, respectively.

4. RESULTS

Based on earlier studies, it has been shown that the overall evaporation quality resulting from flashing increases with time and is influenced by both the initial liquid volume and superheat. Fig.2(a) indicates a significant and rapid decrease in pressure conditions within the flashing chamber. As a result, gas or vapour initially present in the flash tube is transferred to the vacuum tank, leading to a fluctuation in the vacuum conditions. Fig.2(b) illustrates the evolution of water film temperature with time at initial film temperature. It is evident that, within the experimental range, regardless of the initial water temperature, the overall trend of temperature change over time and the temperature gradient during a specific period remain largely consistent throughout the flash process.



(a) Pressure variation. **(b)** Different stages of flashing.

Fig. 2. Variation of pressure and temperature at different experimental conditions.

4. CONCLUSION

I. The change in the transient liquid temperature and intensity is affected by the initial liquid temperature, initial back pressure and initial liquid film height.

II. Flashing is categorized into two stages based on the intensity of evaporation.

III. The liquid film height during the flash affects the final equilibrium temperature in the form of saturation temperature.

IV. The high-speed camera images indicate an increase in the degree of superheat and effect the final height of water remaining in the vaporization chamber after flashing.

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