

Influence of Initial Temperature on Flashing Evaporation

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Abstract. Flash evaporation is widely used in industrial application, such as desalination. An experimental device has built to study the flash evaporation of pure water. The flash experiments were carried out with an initial water height of 0.44 m, initial temperature ranging from 50 °C to 98 °C, and superheat between 4 K and 15 K. The influence of initial temperature on flash evaporation was analyzed. Results suggested that increasing the initial temperature could accelerate the water temperature drop of flashing process, and the evaporated water mass increases with the initial temperature. The study could provide further theoretical support for flash evaporation in industrial applications.

Nomenclature

NEF	non equilibrium fraction [-]
$T(t)$	temperature of water at a certain temperature[°C]
T_e	equilibrium temperature [°C]
T_0	initial temperature of the water [°C]
t^*	flash time [s]
m_g	evaporated mass [kg]
ΔT	degree of superheat [K]
H_0	initial water height [m]

1. Introduction

Flash evaporation refers to a process in which a liquid is heated to a certain temperature and suddenly depressurized below its saturation pressure; part of the water vaporizes into steam. Due to the ambient pressure suddenly drops below the saturated pressure corresponding to the current temperature of the liquid, the liquid changes from the saturated or overcooled state to superheat. As the sudden phase change, all the heat cannot be contained in the liquid as sensible heat, and the heat surplus is transformed into latent heat of vaporization. Compared with simple evaporation, both the rate and the intensity of flash evaporation are quite high. Therefore, flash evaporation is widely used in industrial application, including marine steam accumulator, desalination, and geothermal power generation [1, 2].

In order to apply flash evaporation widely in the industry, it is of necessary to have a better understanding of the basic mechanism of flash phenomenon. At present, it is generally believed that the initial conditions have a great influence on the flashing process. In addition, the water temperature

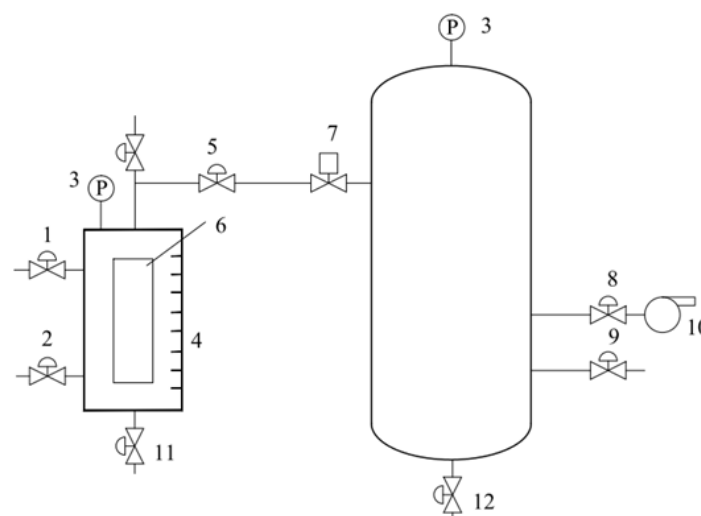


variation and distribution in the flashing process receives wide attention. Since Miyatake, O. [3] defined the dimensionless number *NEF* (non-equilibrium temperature fractions), many researchers have studied it as an important parameter to evaluate the evolution of flash evaporation.

J. I. Kim et al. [4] investigated the non-equilibrium temperature differences at an initial temperature of 40 °C to 80 °C, the superheat from 2 K to 7 K, and a water height of 380 mm. The *NETD* decreases with the increase of the initial temperature and superheat of waterfilm. This value also slightly decreases with decreasing water height. D. Saury et al. [5, 6] conducted experiments about flash evaporation with waterfilm heights between 15 mm and 250 mm. The evaporated mass increase with the rise of the initial temperature and the initial waterfilm height. The correlations were obtained to calculate the evaporated mass and waterfilm height. Y. L. Guo et al. [7] studied the effects of initial water temperature, superheat, and water level on the pool water flash evaporation in the square chamber. The experiments were carried out at initial water level of 40mm, 60mm, 100mm and 150mm, initial water temperature ranging from 50 °C to 88 °C, and superheat between 3 K and 35 K. They found that at a certain initial water temperature, the higher the degree of superheat, the faster the rate of temperature drop. It means that the flash phenomenon is more intense with increasing superheat. The initial water temperature has no effect on the evolution of water temperature over time. The water temperature drops slowly as the initial water level increases. Besides, the correlation between water temperature and initial water temperature, initial superheat, and initial water level was obtained.

2. Experimental setup

The flash evaporation experimental device is shown in Figure 1. It mainly includes the flash evaporation system, the back pressure system, the connection pipeline, the test system, and the observation system. The flash chamber is made of carbon steel, with a sectional diameter of 163mm and cylinder height of 960mm. Two symmetrical quartz glass windows are set at the front and back of the flash chamber, with a height of 510 mm and a width of 80 mm. The vacuum tank is cylindrical, with a cross-sectional diameter of 940 mm and a cylinder height of 1900 mm. In order to ensure that the back pressure remains stable in the depressurization process, the volume of vacuum tank is designed to be 80 times the volume of the flash chamber. The CCD camera is used to observe and record the flashing phenomenon during the experiment. In the flash chamber, 9 fiber grating temperature sensors are arranged along the wall of the cylinder to measure the temperature of the vapor and liquid during flash evaporation process. The pressure sensor is installed upon the flash chamber and the vacuum tank. Temperature data and pressure data are recorded by the data acquisition system.



(1)water filling valve; (2)intake valve; (3) pressure transducer; (4) fiber sensor; (5)adjusting valve; (6) visualization window; (7) electromagnetic valve; (8) vacuum valve; (9)air intake valve; (10)vacuum pump; (11-12) drain valve.

Figure 1. Experimental setup.

In the experiments, the distilled water in the flash chamber is heated to the specified temperature by heating steam; the water height in the flash chamber is adjusted to the required height. The vacuum pump generates the required pressure in the vacuum tank, and the initial pressure in the flash chamber is adjusted by the regulating valve. After all preparations are completed, the data acquisition system starts. When the electromagnetic valve is opened, the flashing occurs in the flash chamber. During this process, the CCD camera records the flashing phenomenon through the visualization window in front of the flash chamber. Meanwhile, the temperature and pressure inside the flash chamber are recorded via the data acquisition system in real time.

3. Result and analysis

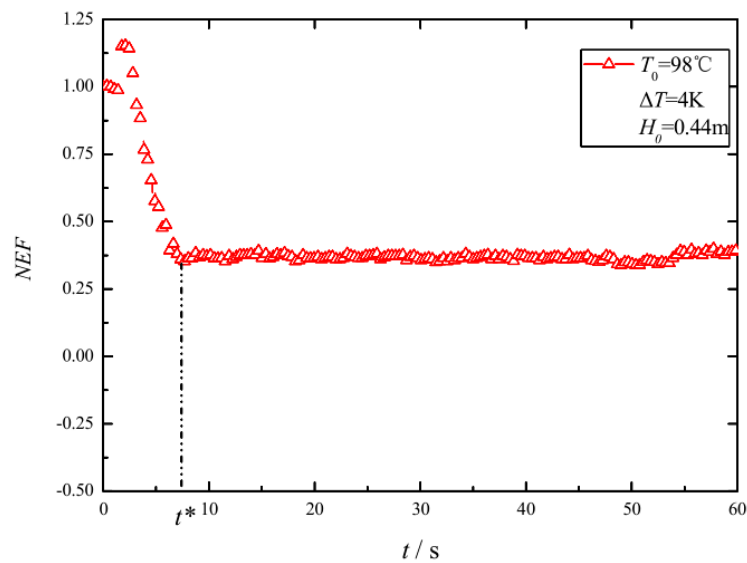


Figure 2. *NEF* evolution.

$$NEF = \frac{T(t) - T_e}{T_0 - T_e} \quad (1)$$

Figure 2 gives an example of the *NEF* evolution versus time. The figure shows that *NEF* can be divided into two stages according to the slope. The first stage decay rapidly and the followed one is more gradual. With the definition, the flashing time t^* is defined as intersection of these two slopes. The experimental results are in good agreement with the Miyatake, O's and D. Saury's [3, 5]. The *NEF* is defined as the ratio of the temperature difference and the maximum temperature difference at a certain time of flash evaporation. It characterizes the evolution of temperature during the flashing phenomenon. Besides, it is a dimensionless parameter to evaluate completeness of flash evaporation.

3.1. Effect of initial temperature on NEF

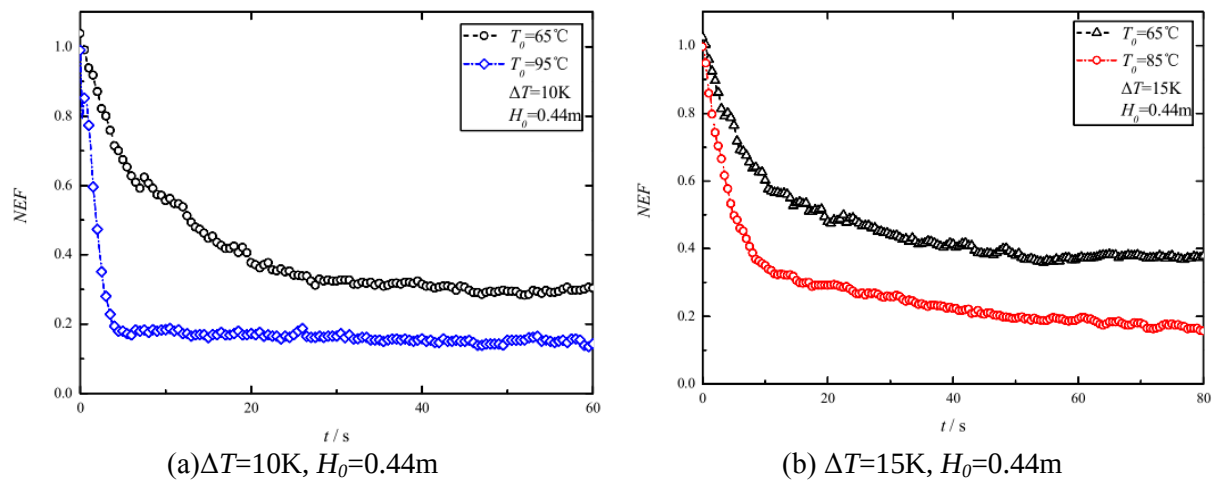


Figure 3. NEF evolution under different initial temperature.

Figure 3(a) shows NEF evolutions under the superheat of 10 K, the water height of 440 mm, and the initial water temperature is 65°C and 95°C , respectively. It can be clearly seen that when the superheat, water height are constant, the first stage of the flash evaporation process with a higher initial temperature has a greater rate of decline. Thus, it results in reducing flashing time and accelerate evaporation rate. The reason is that the initial temperature increases, leading to an increase of the pressure difference between the inside and outside of the bubble. The bubble generation also raises, which promotes the mixing and convection within the liquid and accelerates the flashing process. The case of superheat of 15 K is shown in Figure 3(b), which is consistent with the superheat of 10 K.

3.2. Effect of initial temperature on flash time

A great number of experiments have shown that flash evaporation consists of two stages. The first stage evaporates rapidly and violently. A great amount of bubbles are generated, but it do not last long. The second stage of flashing occurs on the surface of the liquid and has a relatively long duration. Compared with the first stage of flashing phenomenon, the influence of the second stage is negligible, so the turning point time of the NEF is taken as the flashing time t^* . As shown in Figure 4, it indicates that the higher initial water temperature, the faster the flashing. The difference is about an order of magnitude. In previous literatures, the effect of initial temperature on flash time is neglected. However, in this paper, when the other conditions are the same, the initial temperature difference is up to 42°C , the flashing time differs greatly. This suggests that the effect of the initial temperature on the flash time cannot be ignored.

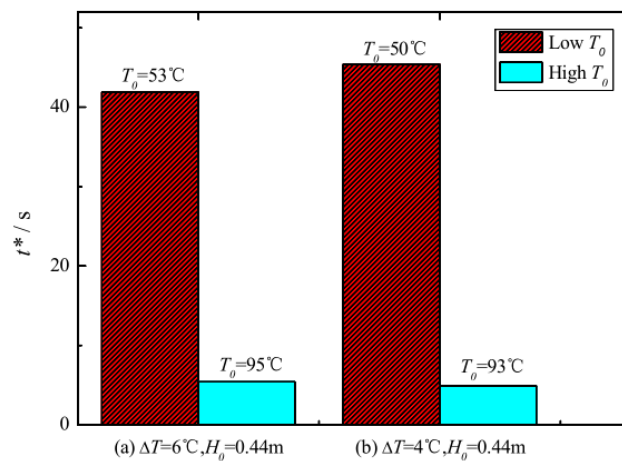


Figure 4. Flash time under different initial temperature.

3.3. Effect of initial temperature on evaporated mass

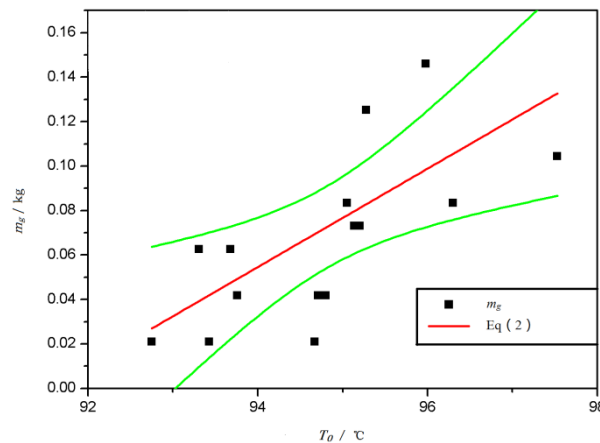


Figure 5. Evolution of m_g versus initial temperature.

The initial temperature is an important parameter affecting the evaporated mass. It and superheat effects the flashing process together. Figure 5 shows the evolution of the evaporated mass with the initial temperature under the initial water height of 440mm. It conforms that the evaporated mass increases as the initial temperature increases. The evaporated mass is an increasing function of the initial water temperature if we consider that the water height variation is negligible. The result is in agreement with D. Saury's conclusion. As a result, the following empirical law is obtained

$$m_g = 0.02214T_0 - 2.02662 \quad (2)$$

4. Conclusion

In this paper, a series of flash evaporation experiments were carried out at an initial temperature between 50 °C and 98 °C, the superheat ranging from 4 K to 15 K, and a water height of 440 mm. These experiments identified the influence of the initial temperature on *NEF*, flash time and the evaporated mass during the flash evaporation. The flash phenomenon was observed using a CCD digital camera and the visualization window. The following conclusions were obtained.

The evaporation vaporization mass is proportional to the initial temperature and increases with the initial temperature, which is in good agreement with D. Saury's conclusion. In addition, the influence of the initial temperature on the flashing time is discussed. It is found that the influence of the initial

water temperature on the flashing process cannot be ignored. The initial temperature is higher, the flashing time is less, and the flashing phenomenon is more intense. As the initial temperature increases, the *NEF* evolution decreases more rapidly and reaches equilibrium state more quickly.

5. Acknowledgement

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6. References

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