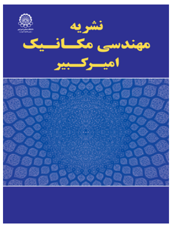


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# Pool Boiling Simulation on Vertical Plate with Triangular & Circular grooves


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**ABSTRACT:** Today, pool boiling heat transfer is used in many industrial equipment and engineering applications. Pool boiling heat transfer compared to single-phase heat transfer has a higher heat transfer capacity due to the use of latent heat evaporation of liquids. Therefore, in this study, the pool boiling heat transfer on a flat vertical plate and plate with triangular and circular grooves have been investigated using numerical simulations. In studies, the effect of adding two types of triangular grooves, two types of circular grooves with different dimensions, and four heating surface temperatures has been investigated. In order to simulate the two-phase flow in this study, the volume of the fluid method was used and the governing equations were solved using the finite volume method. The obtained results showed that adding triangular and circular grooves on the heating surface will increase the average heat flux. In the triangular grooved surface case, the average heat flux which entered liquid increased from 128% to 177%. By using a circular groove, the average heat flux augments about 69% to 105%. Also, the water vapor value in the triangular grooved surface case increased from 160% to 340%, and in the circular grooved surface case rises 101% to 155%.



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## 1- Introduction

The boiling process is an effective method of heat transfer between a surface and the fluid in contact with the surface. In fact, boiling involves evaporation at the solid-liquid interface and occurs when the surface temperature surpasses the saturation temperature corresponding to the liquid pressure.

Gheitaghy et al. [1] studied the effects of horizontal, 45°, and orthogonal surfaces on heat transfer efficiency in pool boiling. They stated that the orthogonal heating surface had the highest critical heat flux, showing an increase of 170% compared to the horizontal one. In an experimental study, Chuang et al [2] investigated the effects of surface orientation on pool boiling heat transfer, wall heat flux, and bubble dynamics. Their results indicated that based on boiling curves measured at different orientations, the boiling heat transfer increased with the increase in the heating surface inclination from 0° to 90°. Nasiri et al. [3] experimentally examined the effects of a grooved surface on pool boiling of $\gamma$-$Fe_2O_3$/water Nanofluid. The results confirmed that the water heat transfer coefficient augmented in rectangular and circular grooved surfaces. Jamialahmadi et al. [4] measured the critical heat flux of CuO nanofluid on the surface of a copper plate in experimental conditions. The results illustrated that with an increase in the concentration of copper oxide nanofluid, critical heat flux increased up to 92% compared to water. Hassani and Kouhi-Kamali [5] carried out a two-dimensional simulation of nucleation pool boiling and investigated the phase change mechanisms in low heat flux. They investigated factors like bubble generation and separation methods, bubble movement, and the flow around bubbles under different conditions.

The present study investigated the effects of triangular and circular grooves on a vertical heating surface in pool boiling. Therefore, a two-dimensional numerical simulation of a pool boiling on a vertical surface with different grooves was carried out for the first time in this study.

## 2- Methodology

In this study, the geometry presented by Chuang et al. [2] was used to conduct a two-dimensional numerical simulation of pool boiling on triangular and circular grooved vertical surfaces. The geometry of this problem is two-dimensional with a rectangle (width= 6 cm and height=20 cm). Fig. 1 shows the dimensions of the triangular and circular grooves created on the heating surface.

Fig. 1. Triangular and circular grooves dimensions

The Volume of Fluid Method (VOF), which is widely used to simulate fluid/fluid interfaces, was used to simulate immiscible two-phase flows. In other words, the VOF works well when the simulation aims at studying the interface of two fluids. In this model, two continuity equations were solved for liquid water and vapor phases [6]:


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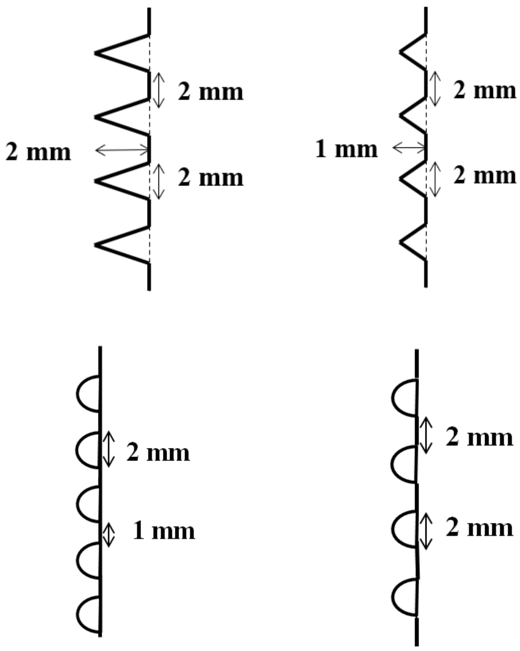


**Fig. 1. Triangular and circular grooves dimensions**

$$\frac{\partial}{\partial t}(\alpha_f \rho_f) + \vec{\nabla}.(\alpha_f \rho_f \vec{v}_f) = S_f \quad (1)$$

$$\frac{\partial}{\partial t}(\alpha_g \rho_g) + \vec{\nabla}.(\alpha_g \rho_g \vec{v}_g) = S_g \quad (2)$$

$S_f$ and $S_g$ stand respectively for the mass source of liquid and vapor phases. The momentum equation depends on volume fractions in different phases with due regard to density and dynamic viscosity values. This equation is as follows:

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \vec{\nabla}.(\rho \vec{v}\vec{v}) = -\vec{\nabla}p + \vec{\nabla}.[\mu(\nabla \vec{v} + \nabla \vec{v}^T)] + \rho \vec{g} + \vec{F} \quad (3)$$

The energy equation common among different phases was:

$$\frac{\partial}{\partial t}(\rho E) + \vec{\nabla}.\left(\vec{v}\left(\rho E + p\right)\right) = S_e + \vec{\nabla}.[k_{eff} \vec{\nabla} T] \quad (4)$$

In this study, a transient simulation of pool boiling was done on a plain surface with vertical, triangular, and circular grooves to investigate the effects of such grooves on the behavior of water liquid in the pool boiling regime. The temperature of the heating surface in numerical simulations was higher than the boiling temperature of liquid water and was equal to 378.15 383.15, 388.15, and 393.15 K in different situations. The acceleration of gravity in the vertical direction (9.81 m/s$^2$) was taken into account.

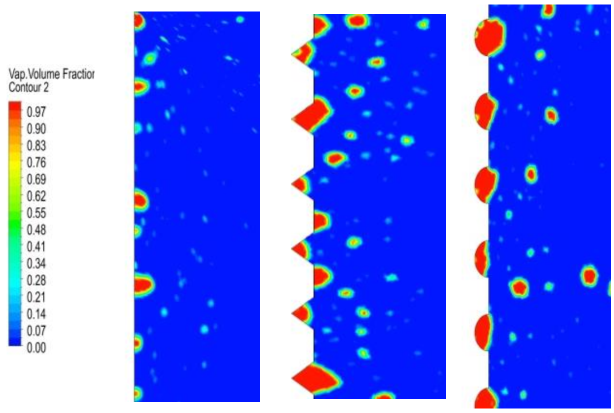


**Fig. 2. Vapor volume fraction variations distribution at t=4s near the heating surface**

## 3- Results and Discussion

To investigate the effects of grooves on the heating surface, bubble formation, and movement were studied at different times.

Fig. 2 shows that many bubbles containing vapor with a temperature and pressure higher than the surrounding water liquid moved upward due to the buoyancy force. Some of these small bubbles merged at this stage, creating larger bubbles. However, the growth rate of the formed vapor bubbles is affected by the surface tension, water inertia, and the difference between the pressure inside and outside the bubble.

The results show that the average heat flux of the water increased with the increase in surface temperature. This was observed for all surfaces investigated. Moreover, the results of numerical simulations showed that applying triangular and circular grooves on the heating surface led to an increase in average heat flux. Two reasons can be posed for this increase. First, grooves led to an increase in the heating surface in contact with the fluid, and in turn, caused an increase in the heat input based on the boundary conditions applied to the heating surface. The second reason for the increase is that changing the shape of the heating surface from plain to groove increased the bubble nucleation spots on the surface significantly. These spots led to the creation of small bubbles in the grooves that would merge and form bigger bubbles.

The amount of vapor produced in the studied geometry increased with a rise in the heating surface temperature. The amount of vapor also increased at a certain temperature by applying triangular and circular grooves. The grooves also improved heat transfer because they could expand the heating surface area and increase the bubble-forming spots due to surface deformation. Like variations in the amount of heat on different surfaces, circular grooves led to a higher level of heating compared to type 1 triangular grooves, they decreased the amount of vapor. This can be attributed to the fact that triangular grooves can create more bubble nucleation spots.

## 4- Conclusions

Considering the importance of heat transfer in various processes in different industries and given the numerous studies carried out to improve the amount of heat transfer, this study investigated pool boiling on a vertical heating surface. The numerical simulation results showed that adding triangular and circular grooves to the heating surface increased the volume fraction of vapor. Moreover, adding different grooves increased the amount of heat input to the water liquid and in turn, the amount of vapor created. The grooves also decreased the time required for the system to reach stability.

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