# THE LIQUID FLOW THROUGH THE CAPILLARY STRUCTURE MADE OF TRAPEZOIDAL MICRO CHANNELS OF THE MICRO FLAT HEAT PIPE

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**Abstract:** *The knowledge about the flow of the working fluid, in the case of micro flat heat pipes (MTTP) with internal capillary structure made of trapezoidal micro channels, is necessary for improving the heat transfer through it. The majority of MTTP which use as internal capillary structure trapezoidal micro channels, the vapors flow has a movement counter flow of liquid through the capillary. The counter flow movement determines, at the vapors- fluid interface of the micro-channels, a loss of pressure in the liquid. The loss of the capillarity capacity, respectively of pumping then liquid through the trapezoidal micro-channels, may affect considerably the capacity of heat transfer of the MTTP. To the capillary structure of an MTTP formed by trapezoidal micro-channels, it was necessarily to determine the types of the liquid flow, of the vapors, of the Poiseuille number, of the medium speed of the liquid flow but also of the shearing tension at the level of the vapors-liquid interface.*

**Keywords:** *trapezoidal micro channels, Poiseuille number, vapors-liquid interface*

## 1. Introduction.

In the analysis made over the flow of the liquid through the interior capillary structure of the MTTP, made of trapezoidal micro channel, it was considered through the hypothesis that the liquid meniscus made by it, is influenced only by the interior pressure of the vapors. This approach presumes that the speed of the liquid flow is not affected by the speed of the vapor's flow. In this case, the evaporating speed at the vapors-liquid interface is zero. The aim of the study is to determine the medium speed and the Poiseuille number for the liquid flow through trapezoidal micro-channels [Klasing,1999] [Sprinceană,2014].

It is considered that through the trapezoidal micro-channels exists a laminar counter flow of the vapors. At the vapors liquid interface appears a tension of the uniform shearing. The effect produced by the vapors flow at the vapors-liquid interface, can be approached through their friction coefficient related to the speed gradient of the liquid.

## 2. The entering parameters.

The counter flow of the liquid through the trapezoidal micro channels with its' vapors, determine the appearance of a shearing tension at the level of the vapors-liquid interface which make the movement speed on the *y* direction, at a certain moment, to be null. The medium speed determination for the liquid flow after *y* direction can be expressed through the relation [Scott,2000]:

$$v^* = -\frac{\partial p}{\partial y}\frac{\mu_{lic} v}{\delta_l^2} \quad (1)$$

The determination of the form of the vapors-liquid interface (figure 1), can be approximated depending on the Bond number and the contact angle of the liquid meniscus at the wall of the trapezoidal micro channel.

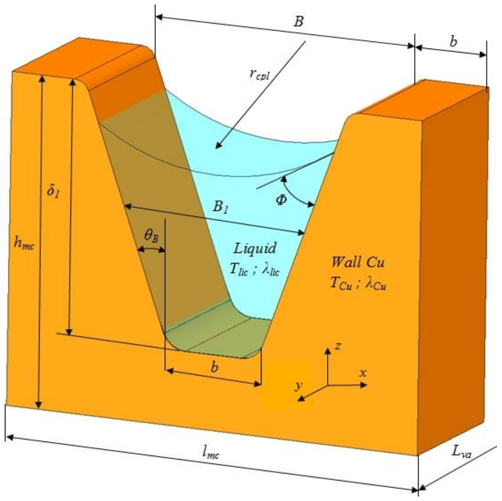



**Figure 1:** *Liquid flow in trapezoidal groove (section).*

It was discovered that the variation of the Bond number influences the friction coefficient of the liquid flow through the trapezoidal micro-channels. The value of the $d_B$ angle, for calculations, is between $0 \div 60°$ and the contact angle of the meniscus $\Phi$, has values between $0 \div 70°$. For the Bond number, this will be calculated after the relation [Klasing,1999] [Scott,2000]:

$$Bo = \frac{\rho_{lic} g \delta^2}{\sigma_{lic}} \quad (2)$$

Where: $\rho_{lic}=996kg/m^3$ the working liquid density (distilled water), $g=9.81m/s^2$ the gravitational acceleration, the coefficient of the superficial tension $\sigma_{lic}=0.0695N/m$, $\delta$ represents the distance from the vapors liquid interface to the bottom part of the trapezoidal micro-channel, the dynamic viscosity $f_{lic}=7.99\cdot10^{-4}Pa\cdot s$, $a_{ll}$ the height of the trapezoidal micro channel.

## 3. The calculation of the Poiseuille number and the medium speed of the liquid vapors.

In the case of liquid flow through the trapezoidal micro channels counter flow with the vapors, the value of the shearing tension the level of the vapors- liquid interface. it will accomplish the following requirement: $\tau_{vl}<0$. If the speed $v$ does not vary after the direction $y$, the pressure gradient $\partial p/\partial y$ is constant. In this case, the moment's conservation equations are reduced to Poisson's classical equation [Scott,2000]:

$$\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial z^2} = \frac{1}{\mu_{lic}}\frac{\partial p}{\partial y} \quad (3)$$

Through the hypothesis, it is considered that the meniscus form is circular and that the vapors-liquid interface presses on them. In figure 2, it was proposed a geometrical model of the liquid meniscus which fills the trapezoidal micro-channels.

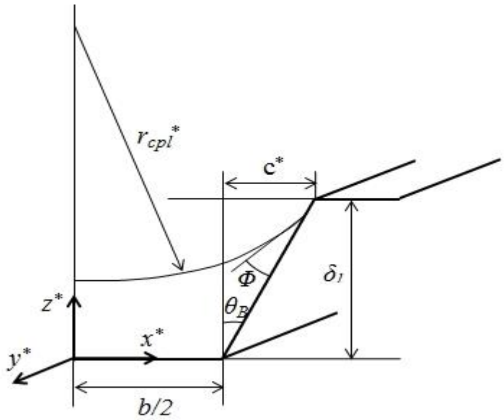



**Figure 2:** *Geometric model proposed for the flow of liquid through trapezoidal micro-channel.*

The values on the height of the liquid in the trapezoidal micro channels which make an interior capillary layer for the MTTP, in the vaporization and condensation area, there were taken into consideration the following results [Mihai1,2017] [Mihai2,2017].

The dimensionless equation of the impulse conservation and the limit conditions originate from (3) [Scott,2000] [White,1991]:

$$\frac{\partial^2 v_{lic}^*}{\partial x^{*2}} + \frac{\partial^2 v_{lic}^*}{\partial y^{*2}} = -1 \qquad (4)$$

In this case, if:

$$\begin{cases} z^* = 0 \ ; \ 0 \le x^* \le \dfrac{b}{2} \\ \theta_B > 0 \ ; \ z^* = \left( z^* - \dfrac{b}{2} \right) \operatorname{ctg} \theta_B \ ; \ \dfrac{b}{2} \le z^* \le \dfrac{b}{2} + \operatorname{tg} \theta_B \\ \theta_B = 0 \ ; \ x^* = \dfrac{b}{2} \ ; \ 0 \le z^* \le 1 \end{cases} \qquad (5)$$

It results $v_{lic}^*=0$.

If the criteria $\theta_B>0$ is satisfied, the dimensionless capillary radius can be express through the relation:

$$r_{cpl}^* = \left( \frac{b}{2} + \operatorname{tg} \theta_B \right) \sqrt{1 + \frac{1}{\left[ \operatorname{ctg} \theta_B - \dfrac{\sin \Phi}{\sin \theta_B \sin(\theta_B + \Phi)} \right]^2}} \qquad (6)$$

The laminar flow determines the apparition of a shearing tension on the vapors-liquid interface, when the vapors are counter flow. It is considered that on the flow direction, the dimensionless value of the shearing tension has the expression:

$$\frac{\partial v_{vap}^*}{\partial y^*} = \tau_{vl}^* \qquad (7)$$

The dimensionless value of the shearing value can be expressed through the friction and medium speed coefficients of the vapors for the following flow cases:

a) downstream:

$$\tau_{vl}^* = f_{vap} \frac{\rho_{vap} (\overline{v_{vap}^*})^2}{2} \qquad (8)$$

b) counter flow:

$$\tau_{vl}^* = -f_{vap} \frac{\rho_{vap} (\overline{v_{vap}^*})^2}{2} \qquad (9)$$

The medium dimensionless speed of the vapors according to [White,1991] can be expressed through the relation:

$$\overline{v_{vap}^*} = \frac{2}{A_{mc}^*} \int_0^{b/2+tg\theta_B} \int_0^{z^*} v^* dz^* dx^* \qquad (10)$$

To calculate both the dimensionless transversal area of the micro channel $A^*_{mc}$ and the dimensionless hydraulic diameter of the trapezoidal micro channel $D^*_{h,mc}$, it is taken into consideration the condition $\theta_B+\Phi<\pi/2$ and results:

$$A_{mc}^* = \frac{b}{2} + \left( \frac{b}{2} + tg\theta_B \right) \left( 1 + c^* \right) - \frac{r_{cpl}^*}{\cos \dfrac{c^*}{r_{cpl}^*}} \qquad (11)$$

$$D_{h,mc}^* = \frac{2 A_{mc}^*}{\dfrac{b}{2} + \dfrac{1}{\cos \theta_B}} \qquad (12)$$

In this case, Poiseuille can be expressed through the relation:

$$Po = f_{vap} \operatorname{Re} = \frac{\overline{D_{mc}^{*\,2}}}{2 v_{vap}^*} \qquad (13)$$

For the case when $\theta B+\Phi=\pi/2$, it results:

$$D_{h,mc}^* = 2\left( b + tg\theta_B \right) \left( \frac{1}{\dfrac{b}{2} + \dfrac{1}{\cos \theta_B}} \right) \qquad (14)$$

To calculate the medium speed of liquid vapors at the vapors-liquid interface, it was considered that the value of the angle of the liquid meniscus is between $0\le\Phi\le\pi/2-\theta_B$. The values of the medium speed have a linear increase, the same with the shearing tension. The medium speed of the vapors can increase if the angle $\theta_B$ increases with a half value of the angle of the liquid meniscus (the case in which the micro channel cross-sectional area is modified). If the angle $\theta_B$ changes with half of its' initial value, then the medium speed will increase until the contact angle of the meniscus modifies at the same time with the perimeter of the vapors liquid interface.

## 4. The obtained results and their interpretation.

To calculate the Poiseuille number it presumes that the angle $\theta_B$ doesn't modify and has the value *30°*. It was considered that, at the liquid's movement through the micro channel, the contact angle of the liquid meniscus modifies at the same time with the cubical debit. In this case, the increase of the shearing tension at the level of the vapors-liquid interface, produces an accentuated decrease of Poiseuille number. The counter flow influences the value of the medium speed to incline to zero and $\tau^*_{vl}<0$. The modification of the contact angle of the liquid meniscus produces a decrease of Poiseuille number (if it is considered a unique value for $\tau^*_{vl}$). In figure 3 it was graphically presented the evolution of the Poiseuille number according to the variation of the liquid meniscus' angle and the medium speed of the liquid vapors.

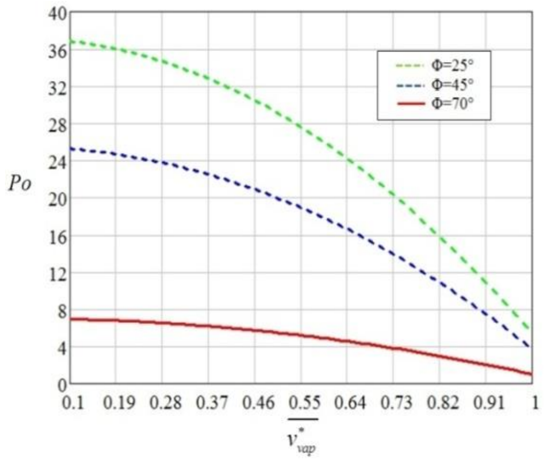



**Figure 3:** *Variation of the Poiseuille number depending on the variation of the meniscus angle and the average vapor velocity.*

To continue, it was calculated the value of the dimensionless hydraulic diameter for different angles of the liquid meniscus. From figure 4 results that, once the angle of the liquid meniscus increases, the value of the hydraulic diameter of the trapezoidal micro channel increases. To calculate the hydraulic diameter, it was considered that the angle's value is $\theta_B=35°$.

The variation of the hydraulic diameter is maximum when the angle of the liquid meniscus is equal with a radian. An increase of the movement speed of the liquid (for the case with downstream when $\tau^*_{vl}>0$) through the trapezoidal micro channels, it determines at the vapors-liquid interface an increase of the shearing tension.

In figure 5, it was graphically presented the variation of the shearing tension at the level of the vapors-liquid interface, for the case when the value of the angle is $\theta_B=45°$ and the one of the liquid meniscus is $\Phi=10°$.

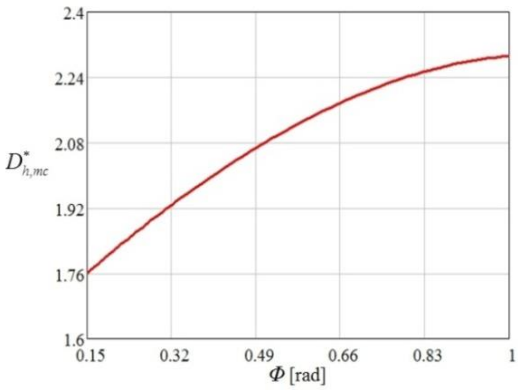



**Figure 4:** *Hydraulic diameter variation depending on the meniscus fluid angle.*

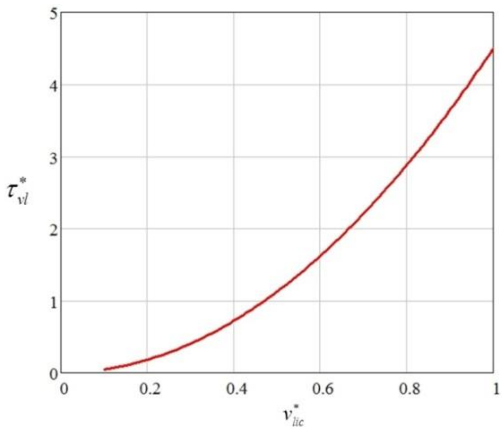



**Figure 5:** *Shear stress variation depending of speed liquid (current flow).*

Since it was chosen the case of downstream, the value of the movement speed of the liquid is positive and the maximum value of $\tau^{*}_{vl}=4.5$. The counter flow of the liquid to the vapors, produces at the level of vapors-liquid interface a negative shearing tension (figure 6).

For the counter flow of liquid with the vapors, the maximum value of $\tau^{*}_{vl}=-0.45$. The values for the angle of the liquid meniscus and for the oblique angle of the micro channel's wall, are the same as in the previous case. The vapors downstream determine a variation of the medium speed according to the angle of the liquid meniscus. To calculate the angle $\theta_B$, there were taken into consideration the values *15°*, *25°* and *35°*.

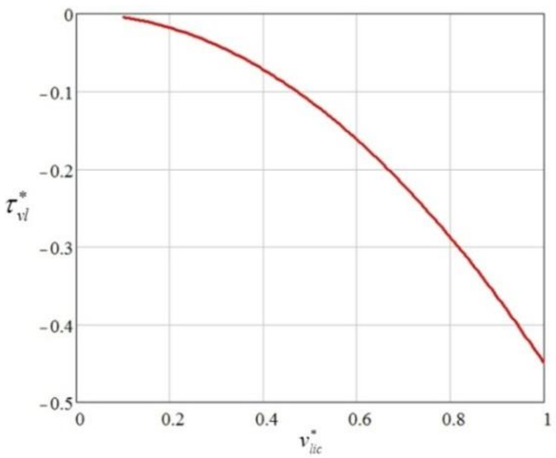
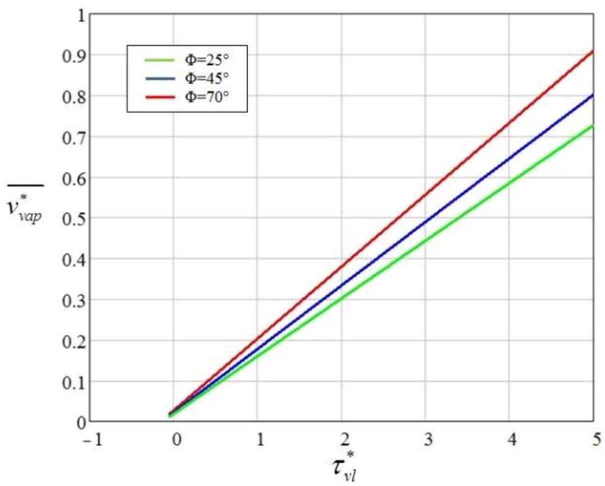
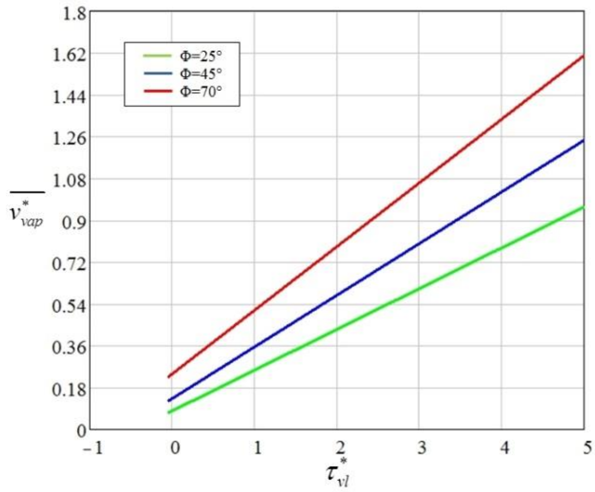



**Figure 6:** *Shear stress variation depending of speed liquid (counter current flow).*

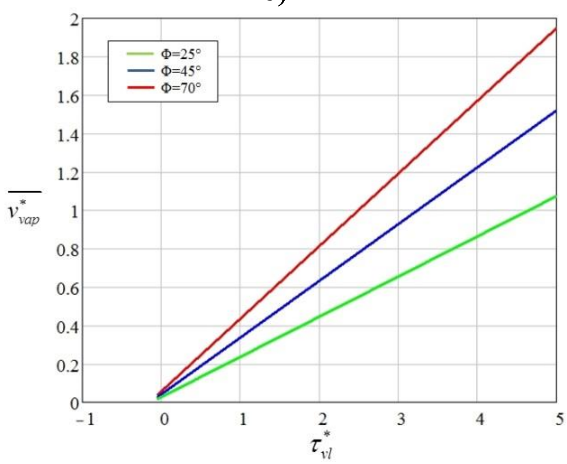
In figure 7-a,b,c it was presented the variation of the medium speed of vapors in the case of downstream.




a)




b)




c)

**Figure 7:** *Mean velocity variation depending on the shear stress: a) $\theta_B=15°$; b) $\theta_B=25°$; c) $\theta_B=35°$.*

At the same time, the variation of the $\theta_B$ angle produces an increase of the medium speed of the vapors through the modification of the transversal area of the trapezoidal micro channel.

## 5. Conclusions.

According to the obtained results through the shaping in the analysis of the liquid flow through the trapezoidal micro channels, there are a few conclusions that were made:

1. For an angle of the liquid meniscus, the Poiseuille number decreases at once with the increase of the medium speed of vapors.
2. The hydraulic diameter of the trapezoidal micro channels increases at

once with the increase of the liquid meniscus angle.

3. The value of the shearing tension for the case of downstream is ascender, respectively descendant, for the case of counter flow, if the angles $\Phi$ has $\theta_B$ fixed values.
4. In the case of vapors downstream reported at the shearing tension, the medium speed has a linear increase for the whole analyzed cases.
5. The value of the medium speed has a linear increase at once with the increase of the contact angle of the liquid meniscus.
6. The value of the medium speed has a linear increase at once with the increase of the transversal area of the micro channel the modification of the angle $\theta_B$).

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