Simulation of the impact of a liquid jet upon contact with a perpendicular surface versus an inclined one

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ABSTRACT

This article will study the impact of a liquid jet with a flat surface, from a dynamic point of view. The surface where the liquid jet impact will take place has been positioned both perpendiculars to the direction of the jet and at a certain angle. To determine how the impact of the liquid jet takes place in the immediate vicinity of the plane plate, a CFD simulation is performed. The obtained results allow us to study two situations, one that concerns the occurrence of the hydraulic jump during the impact and the second will allow us to analyze the evolution of the jet symmetry. It is known that the impact of a liquid jet with a surface is quite complex. To solve this, the VOF (volume of fluid) model was used. The obtained results allow us to visualize the evolution of the liquid jet in the form of a complex geometric shape that at the extremities is followed by a hydraulic jump and the fragmentation of a part. The behavior of the impact of the jet with a surface inclined at 45°, shows that there is an asymmetry of the contact fingerprint as the jet inclines towards the normal straight-line surface. The main objective of the present simulations is to experimentally investigate the effect of the angle of inclination of the jet and of the fluid flow on the initial imprint formed at the contact and on the post-fragmentation mode of the complex geometrical structure formed.

Keywords:

circular hydraulic jump, liquid jet impingement, VOF.

Introduction

Liquid jets that come in contact with a flat surface are a very important topic when it comes to cooling some surfaces. Thus, it is useful to know their evolution in order to optimize the cooling process. Thus, in this work a study was conducted based on simulating a jet of liquid in two different positions, perpendicular and at an angle of 45°. Thus, it was found that as the vertical jet comes into contact with the horizontal plate, an area appears where the liquid layer is thin and suddenly this value increases, it is called hydraulic jump. The position of this jump largely depends on the speed and flow of liquid. There are many studies of hydraulic jump in fluid mechanics manuals[1-3]. In the case of liquid jets positioned at an angle of 45° it can be seen that the hydraulic jump is more pronounced upstream and has the printed shape of an ellipse.

Theoretical approach

Using the formula (1) we study the development of the liquid jet based on the mathematical model of the formation of the a radius and the radius R_s of the jump height H using variations of the flow Q and different values of the radius of the liquid jet. At the impact of a vertical liquid jet on a solid surface[4], a hydraulic circular jump, shown in Fig 1.

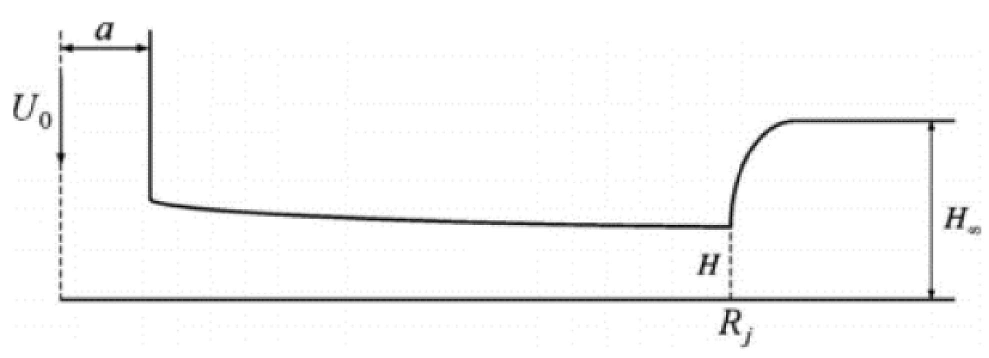

Fig. 1. General structure of circular hydraulic jump[4].

Watson[5], was the first person to analyze the viscous circular hydraulic jump using the boundary layer theory for the upstream jump and assumed flow in the downstream region. Assuming that the pressure force is equal to the rate of destruction of the impulse, he derived the following for the jump state:

$$\frac{1}{2}g\left(H_\infty^2 - H^2\right) = \left(\frac{Q}{2\pi R_s}\right)^2 \left(\frac{1}{H} - \frac{1}{H_\infty}\right) \quad (1)$$

where H - the height upstream, H_∞ - the height downstream or outer depth, g - gravitational acceleration, Q - volume flow, and R_s - jump radius. The result of the invisibility theory in non-dimensional form, obtained by neglecting the term contain in inside Eq. 1 and various substitutions made, it is given by:

$$\frac{R_s H_\infty^2 g a^2}{Q^2} + \frac{a^2}{2\pi^2 R_s H_\infty} = \frac{1}{\pi^2} \quad (2)$$

where a is the entry radius of the jet before impact[6]. Research to date shows that when a liquid jet collides with a sloping wall[4], the formed liquid film thickness is not symmetrical. It has also been found that starting from the minimum portion of the formed liquid film it is found that the opposite diameter will have a maximum asymmetry. For the same flow of liquid jet, as the angle Ψ decreases (fig. 2), the radius of the hydraulic jump increases in the opposite jet inclination area θ=π and decreases when θ=0, and the area delimited by the hydraulic jump increases. There are two situations. If ψ=90° the area bounded by the hydraulic jump is a circular shape and for ψ≠90° the liquid jet formed will have a non-circular shape, according to Fig. 2.

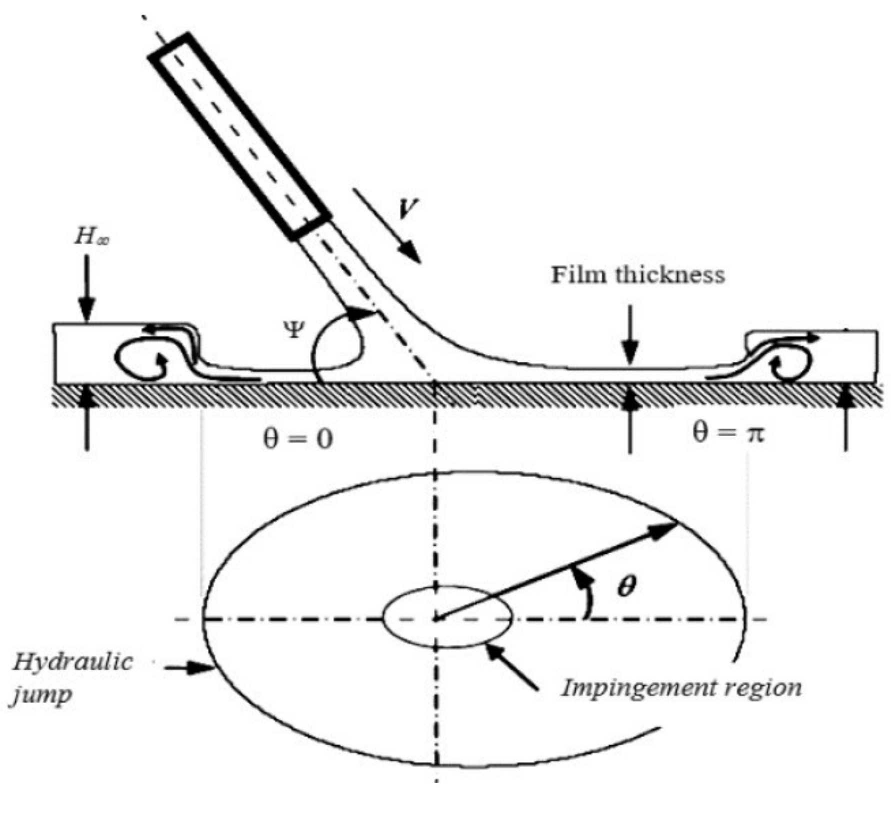

Fig. 2. Elliptical-shaped profile of the hydraulic jump due to the oblique jet hitting the horizontal flat plate[4].

Results and discussion

In Figure 3-4, the symmetry of the jet is analyzed in the case of the 2 positions of the jet. In the first image we observe the footprint left by a jet at an angle[7] of 45°, we can observe the elliptical shape generated by it and in the second image the footprint left by the jet perpendicular to the flat surface.

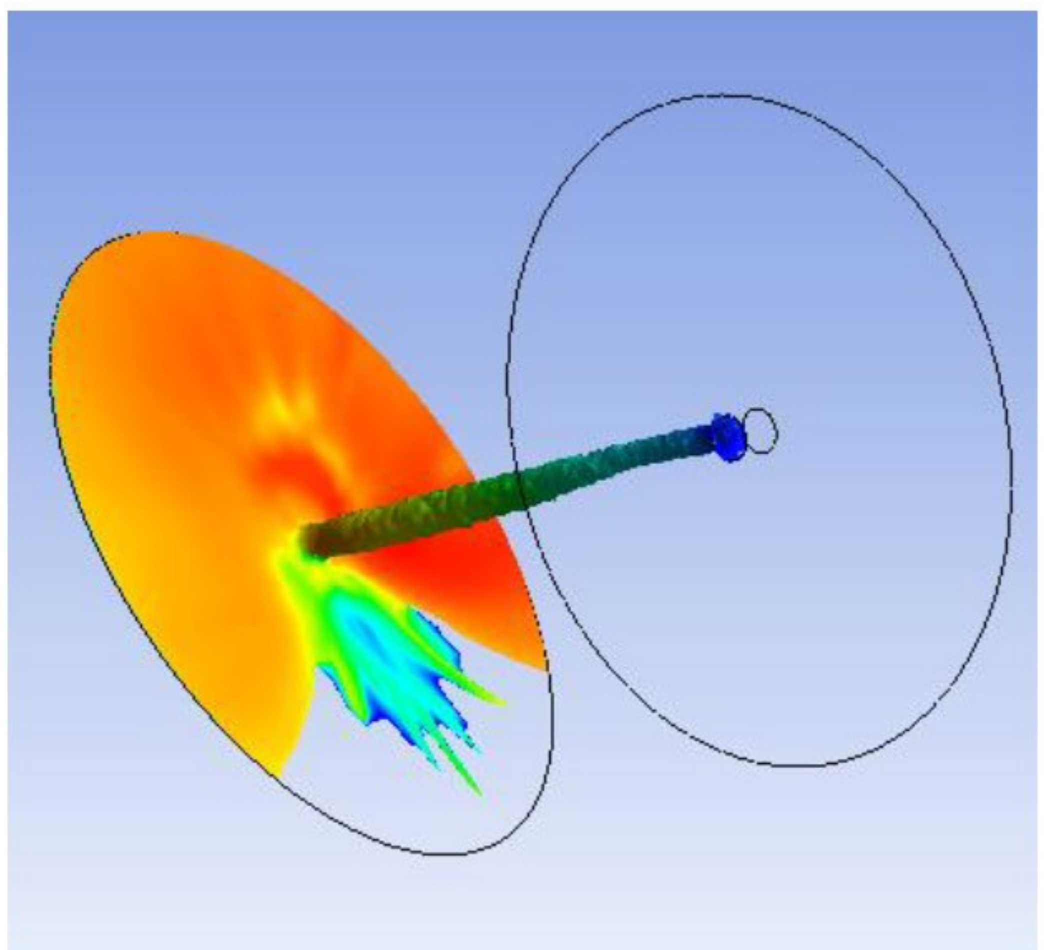

Fig.3. Modeling the impact of the liquid jet on a surface inclined.

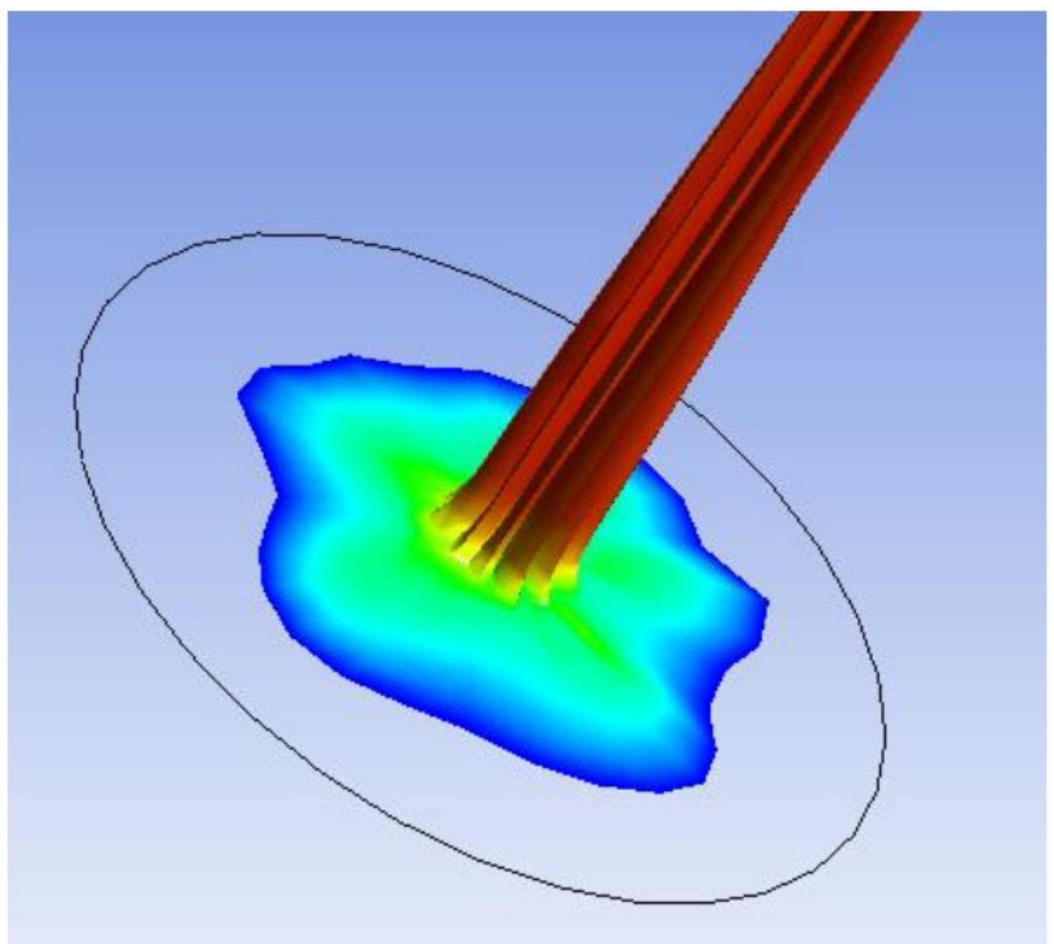

Fig. 4. Modeling the impact of the liquid jet on a surface perpendicular.

When the angle is equal to 45° (Figures 5, 6), all water flow of the jet flows out of the jet radius downstream of the target surface. Due to the speed, a high-speed vortex is created, which is evident over almost the entire jet space in the upstream region.

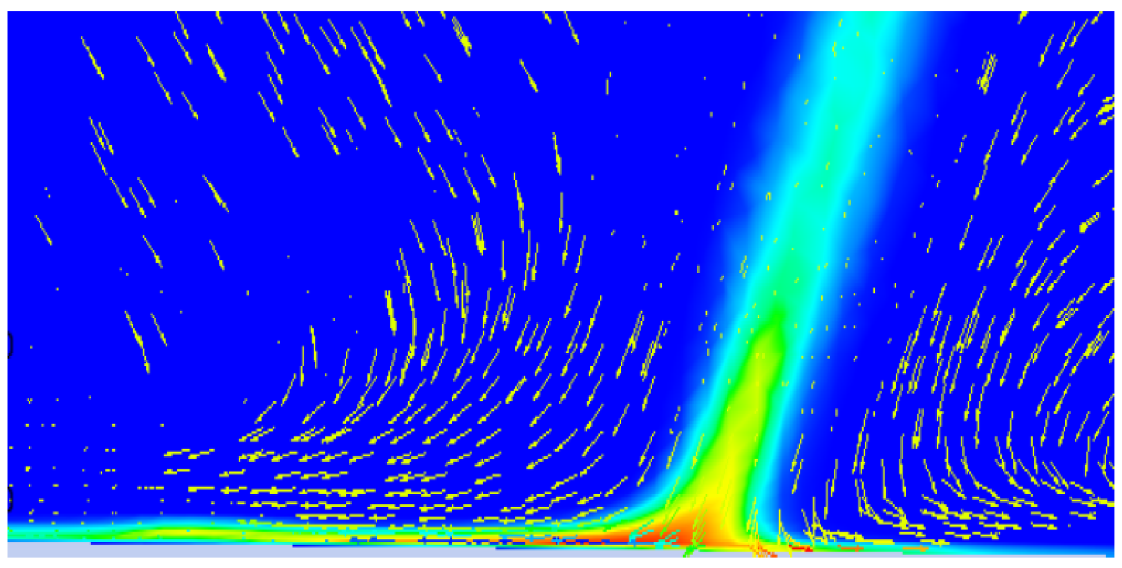

Fig. 5. Velocity vectors in the case of 45° inclined jet.

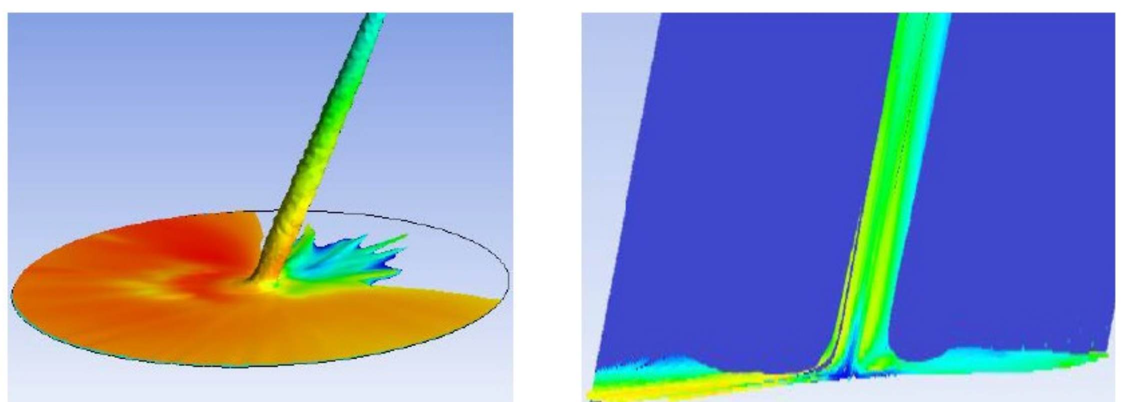

Fig. 6. The evolution of the jet inclined at 45° (a), the hydraulic jump resulting from the simulation (b).

In the downstream region (Figure 6), the flow of water obviously increases, and the jet that impacts with the wall moves outward. The flow of entrainment fluid comes mostly from the upstream region, which suppresses the flow of water in the stagnation zone to develop along the upstream region.

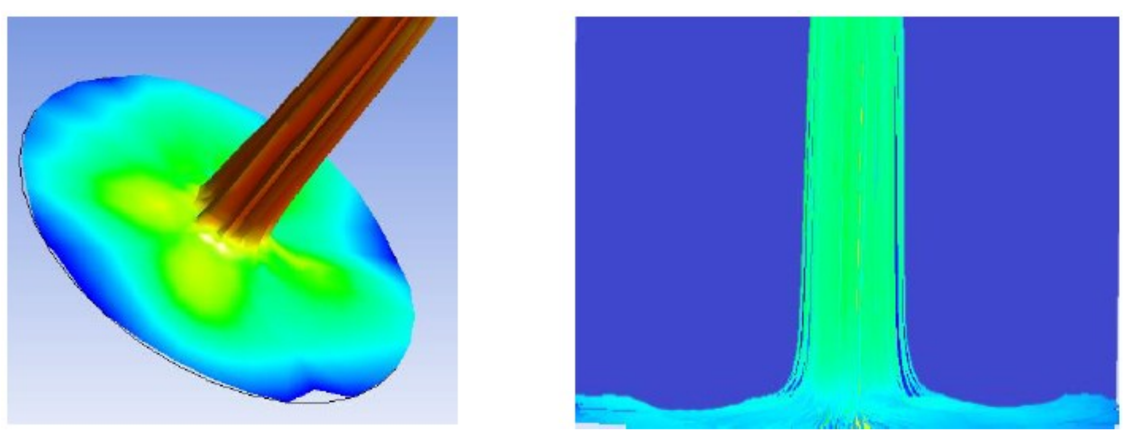

Fig. 7. The evolution of the perpendicular jet (a), the hydraulic jump resulting from the simulation (b).

The notations used are as in[1] (see figure 8), where *q* is the volume flow, *u* are the speed, and a the diameter of the jet at the contact point with the horizontal plate, *h*, *v*, and *H, V* the height and speed of the liquid layer just before and after the hydraulic jump, respectively. We denote the density of the liquid by *r*, the gravitational acceleration by *g*, and the radius of the hydraulic jump by *R*.

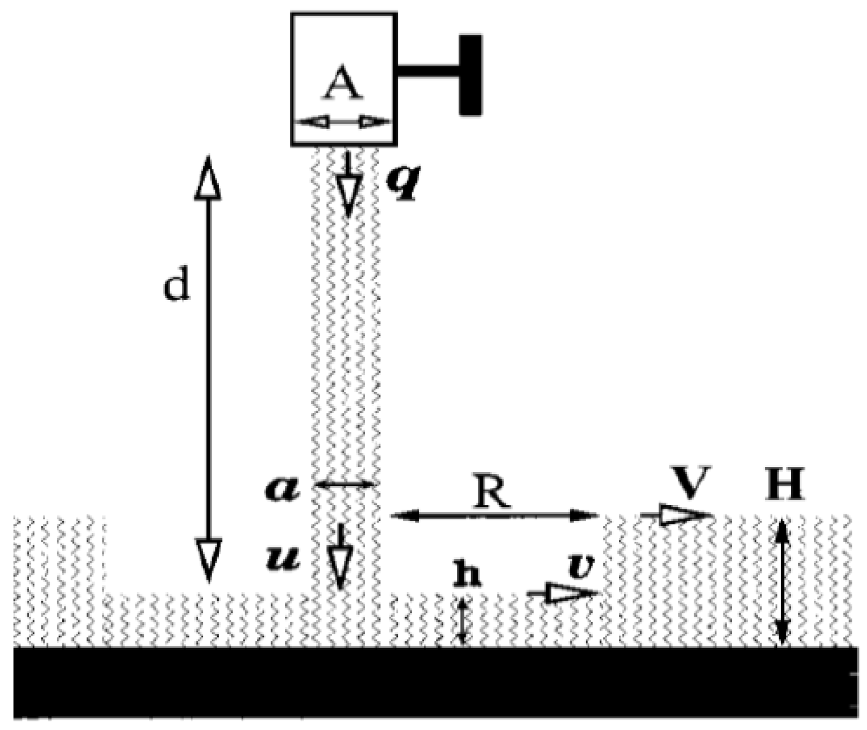

Fig. 8. Notations for identifying points of interest[1].

Figure 9 shows the variation of the radius *R* as a function of the distance of the nozzle d from the flat plate.

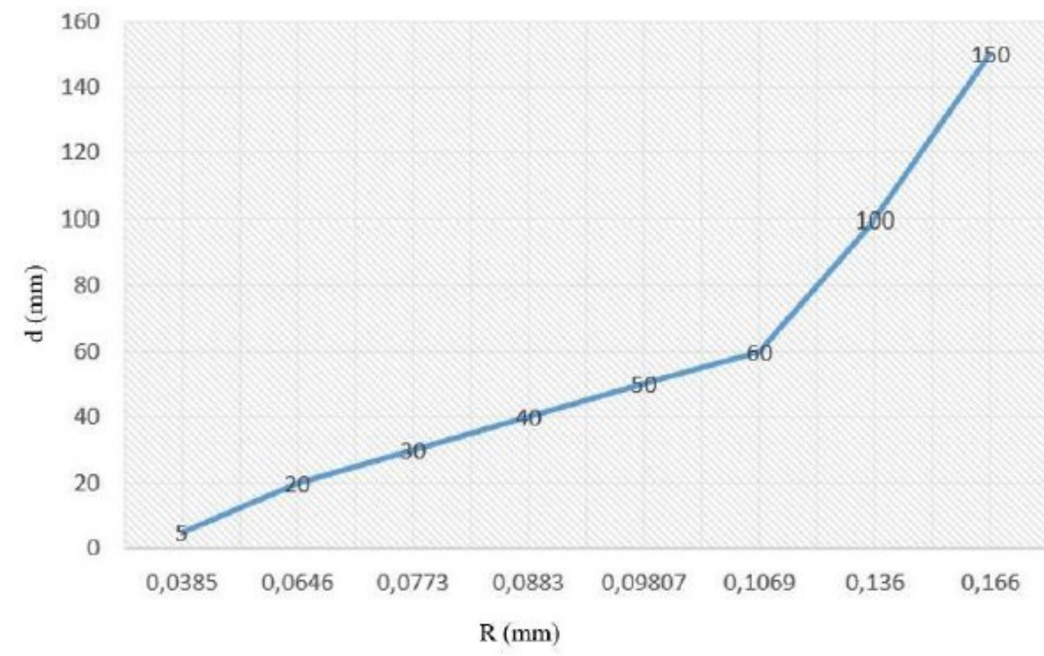

Fig. 9. Variation of the radius *R* as a function of the distance of the nozzle d from the flat plate.

In contrast to the previous case Figure 10 shows how to change the radius *R* of the as a function of the flow rate volume *q*.

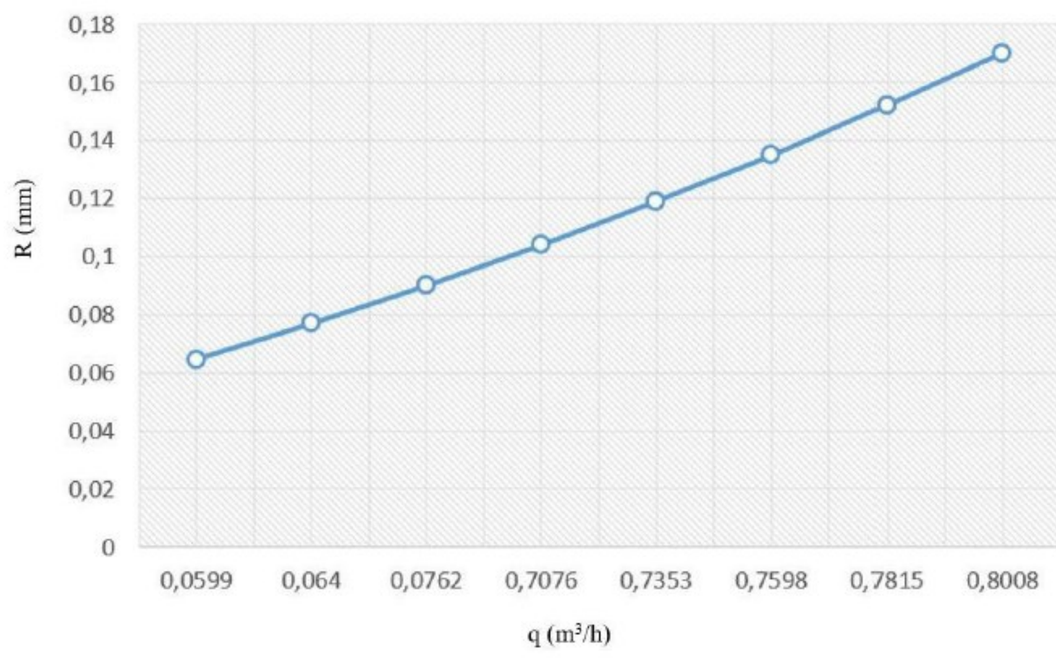

Fig. 9. Variation of the radius R of the as a function of the flow rate volume.

Conclusions

Studies have shown that when a liquid jet collides with a surface, a number of factors are involved that lead to the change of the liquid footprint formed immediately after the impact. One of these factors of influence is the angle under which the jet falls on the wall. The flow of liquid on the other hand, as well as the viscosity of the liquid, apply their imprint on the complex geometrical shape caused by the collision, and on the way in which the liquid sale is fragmented. The impact velocity is defining for the process of forming the liquid stain and the hydraulic jump.

REFERENCES

[1] Brechet, Y., Neda Z., "On the circular hydraulic jump," American Association of Physics Teachers, pp.723-730 (1998).

[2] Acheson D. J., ''Hydraulic jumps and shock waves,'', Elementary Fluid Dynamics - Oxford, U.P., New York, pp. 100–104 (1990).

[3] Whitaker S., ''Hydraulic jump,'', Introduction to Fluid Mechanics, Prentice–Hall, Englewood Cliffs, NJ,, pp. 382–385 (1968).

[4] Passandideh-Fard M., Teymourtash A. R., Khavari M., "Numerical Study of Circular Hydraulic Jump Using Volume-of-Fluid Method," Journal of Fluids Engineering, vol. 133, pp. 011401-1 at 011401-11 (2011). file:///C:/Users/40735/Downloads Numerical_Study_of_Circular_Hydraulic_Jump_Using_V.pdf

[5] Watson, E. J., "The Radial Spread of a Liquid Jet Over a Horizontal Plane," J. Fluid Mech., 20, pp. 481–499 (1964).

[6] Kate, R. P., Das P. K., Chakraborty S., "Hydraulic jumps due to oblique impingement of circular liquid jets on a flat horizontal surface". J Fluid Mech., 573, pp. 247–263 (2007).

[7] Taylor, S. G., "Oblique impact of a jet on a plane surface," Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences, Vol. 260, No. 1110, pp. 96–100 (1966).