Industrial wiping systems: Assessment of shear stress caused by wall jets

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When talking about wiping systems for removing liquids it is inevitable to associate its performance with the pressure produced by the impact of the impinging jet. However, it is also known that, for large surface applications such as continuous strip, the shear stress on the surface plays a fundamental role. This work deals with the assessment of shear stress caused by wall jets on infinite surfaces.

INTRODUCTION

Usually, manufactures of wiping system focus the information supplied on the impingement pressure. However, it is known that the shear stress between the wall jet and the liquid film is critical to reduce the amount of water reaching the proximities of the jet impingement [1]. Among the techniques for assessing the shear stress on a surface, using the so-called Preston tubes appears to be one of the simplest and reliable solution. In [2], J.H. Preston develops a simple method to determine the shear stress on a smooth surface using a simple round Pitot tube of very small dimensions, resting on the surface, see FIG 1. This technique has been used by several authors to measure wall shear stresses in different applications [1][3][4].

This work deals with the development of Preston-based measurements for wall jets shear stress downstream the impingement of a planar jet such as an air knife used in wiping systems.

MATERIALS AND METHODS

The differential pressure obtained by the Preston tube can be expressed in a dimensionless form as follows:

$$\frac{\Delta P_P}{\rho U^{*2}} = f\left(\frac{U^* d}{\nu}\right) \quad (1)$$

Where ΔP_P is the difference of pressure between the measurement of the Preston tube and the static pressure, d is the external diameter of the Preston tube, ρ and ν are the density and the kinematic viscosity of the air, and U^* is the speed friction, which is defined as:

$$U^* = \sqrt{\tau/\rho} \quad (2)$$

Being τ the shear stress in the wall.

In a more practical way, [2] presents the same relation as follows:

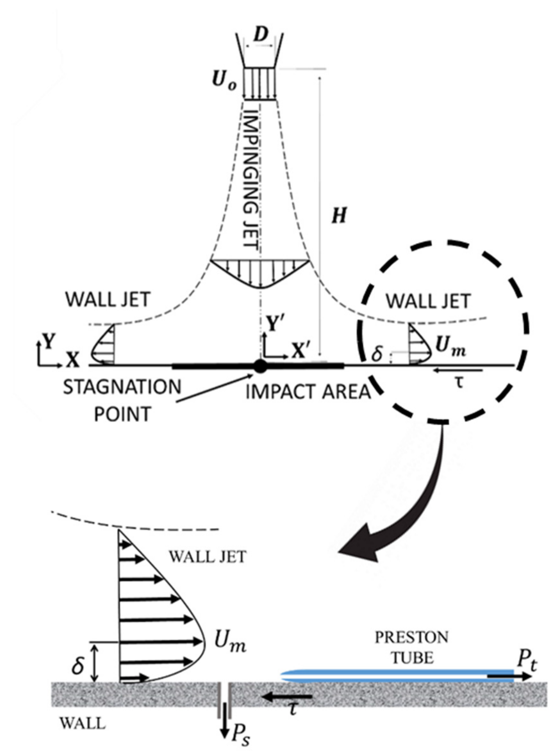

FIG 1. Diagram of the air jet hitting the wall and surface tension measurement (τ) with a Preston probe, where P_t is the total pressure, P_s is the static pressure, U_m is the maximum speed of the wall jet and δ is the distance from the wall to the maximum speed.

$$\frac{\tau d^2}{4\rho\nu^2} = F\left(\frac{\Delta P_P d^2}{4\rho\nu^2}\right) \quad (3)$$

Where the function F is determined based on experimental measurements made in fully developed flow pipes [2][5].

[5] refines the Preston method and presents some calibrated curves that complete the use of this type of tubes. This correlation of the measurements is commonly called Patel's correction. It changes the equation 3, in logarithmic form, as follows (equation 4):

$$x^* = Fy^* \quad (4)$$

Where:

$$x^* = log\frac{\tau_o d^2}{4\rho v^2}\ ;\ y^* = log\frac{\Delta P_P d^2}{4\rho v^2} \quad (5)$$

By means of the equations obtained experimentally by [5] (equations 6 and 7), the function F is solved and the value of the shear stress in the wall (τ) is obtained.

$$if\ 2.9 > x^* < 5.6$$
$$y^* = 0.8287 - 0.1381x^* + 0.1437x^* - 0.0060x^* \quad (6)$$

$$if\ 0 > x^* < 2.9$$
$$y^* = 0.5x^* + 0.037 \quad (7)$$

An air-knife with total dimensions of 200x100 mm (length and height) and a gap nozzle (*D*) of 2 mm, has been used in order to carry on the test. This device is fed bilaterally to minimize the feeding effects, and the values of shear stress were taken from the middle point of this length. The pressure inside the air-knife during the test was 2 kPa.

To obtain the pressure magnitudes on the test bench, pressure measurements will be made at different distances from the jet impact line by means of Preston tubes with an outer diameter of 0.2 mm and an inner diameter of 0.1 mm, which will provide pressure values at a height of 0.1 mm above the wall.

RESULTS AND DISCUSSION

The experimental results of wall shear stress have been obtained for an air-knife with a gap nozzle of *D*=2 mm, blowing at different distances. The results obtained are shown in a dimensionless form in FIG 2.

As can be seen, the point of higher shear stress is closer to the maximum pressure point (that is located at *X/b*=0, corresponding with the impinging line) as the blowing distance is smaller. Moreover, as it can be expected, the air-knife blowing from a lower blowing distance generate a higher shear stress at lower values of *X/b* but, in *X/b*=16 all of the configurations collapse, having the same wiping effect at this point. These results are in agreement with the bibliography.

CONCLUSIONS

Shear stress analysis is essential for a complete characterization of a wiping system. One of the most used methods for obtaining the values of wall shear stress in air jets, is the utilization of a Preston tube.

In this work, Preston tubes are used in order to compare an air-knife blowing at different distances. As a conclusion, smaller distances produce a higher wall shear stress at values of *X* closer to the impinging line (located at *X*=0 mm). However, far from the impinging line (at higher values of *X*), the shear stress collapse and the performance of all the configuration of wiping systems (changing the blowing distance), is almost the same.

In the near future tests will be carried out not in a planar jet, but an array of multiple hole planar nozzles in order to characterize the performance of wiping systems based on them.

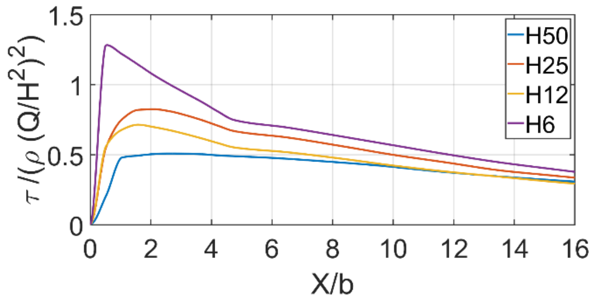

FIG 2. Comparison of wall shear stress values (τ) on different blowing distances (H=50/25/12/6 mm) for Re=2394. Values presented in a dimensionless form, being b the half-width of the impingement pressure profile, Q the flow rate and H the blowing distance.

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