CAVITATION AND DISSIPATION EFFICIENCY OF MULTIHOLE ORIFICES

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ABSTRACT

This paper describes the first series of experimental results of a research aimed at the investigation of pressure loss and cavitation characteristics of multihole orifices by means of the measure of its effects, such as vibrations and noise. Moreover, the tests involve pressure, flow rate and temperature measurements.

We focus on dissipation efficiency and cavitation condition of multihole orifice as a function of its geometry. We analyse several 3" resistors, changing the main geometric characteristics, such as number, diameter, bevel and placement of the holes. Tests have been performed in agreement with ISA-RP75.23-1995 normative.

1. INTRODUCTION

Multihole orifices are normally used within pressurized systems, as control and maintenance devices. It is well known that the most appropriate choice and the correct sizing of a control device are fundamental and require a deep knowledge of its hydrodynamic performances.

Several studies have been presented in technical and scientific literature about the multihole orifices performance. Especially the pressure losses in fully turbulent flow and the arising of cavitation conditions are discussed. Idelchik (1986) and Miller (1990) proposed two different analytical formulae for the pressure losses estimation in fully turbulent flow; Tullis and Govindarajan (1973) and Ball *et al.*(1975) studied the pressure scale effects on cavitation; Fratino *et al.* (1990 and 2000) investigated the influence of the multihole orifices geometric characteristic on the pressure losses and on the cavitation development.

Starting from the theoretical background and from the literature studies about the phenomenon, the parameters involved in pressure loss due to multihole orifices can be express by the following dimensionless expression:

$$\Pi = f\left(\frac{D}{d_h}, \frac{s}{d_h}, \vartheta, \mathrm{Re}, \frac{P_{vap}}{\rho V^2}, \frac{P_u}{\rho V^2}\right) \quad (1)$$

where Π is the dimensionless loss coefficient which is expressed by

$$\Pi = \frac{\Delta p}{0.5 \rho V^2} \quad (2)$$

Equations (1) and (2) contain all the significant parameters affecting the phenomenon: D represent the pipe diameter; d_h the diameter of a single hole; s the thickness of the orifice; ϑ the shape parameter, considers the number n, the bevel and distribution of holes; Re the Reynolds number referred to the pipe diameter; P_{vap} the vapour pressure of the fluid; ρ the fluid density; V and P_u the mean flow velocity and the pressure upstream the orifice, while ΔP is the difference between P_u and the pressure downstream the orifice, P_d .

In fully turbulent condition, pressure loss is mainly due to the contraction and expansion of flow depending on area ratio. In literature, this ratio is usually named *contraction ratio* (β) and it is expressed by the following equation, in which also the number of holes, n, is considered.

$$\beta = \frac{\sqrt{n} d_h}{D} \quad (3)$$

Another significant parameter for the phenomenon description is the ratio between thickness and diameter of hole, s/d_h. The value assumed by this parameter divides orifices in two typologies: long orifices with s/d_h >0.015 and thin orifices with s/d_h <0.015. Fratino *et al.* (2000) remarks that both the head losses and the flow pattern downstream the orifices are significantly influenced by s/d_h.

As before mentioned, Idelchik (1986) and Miller (1990) proposed equations modelling the loss coefficient Π.

Idelchik (1986) experimentally derived an expression of the loss coefficient Π, valid for

$Re>10^5$ and for $s/d_h>0.015$:

$$\Pi = \frac{0.5\left(1-\beta^2\right)+\tau\left(1-\beta^2\right)^{1.5}+\left(1-\beta^2\right)^2}{\beta^4}+ \qquad (4)$$
$$+\frac{\lambda\, s/d_h}{\beta^4}$$

where

τ is a tabular data and depend on s/d_h

λ is the friction factor of the hole.

Miller (1990) introduced a correction coefficient in the one dimensional continuity momentum. Equation (5) is the formulae proposed by Fratino (2000) of the Miller's equation where C_0 is the correction coefficient to consider the effect of the ratio s/d_h in fully turbulent condition and α is the contraction coefficient.

$$\Pi = \frac{C_0\left(1-\alpha\beta^2\right)^2}{\alpha^2\beta^4} \qquad (5)$$

The mentioned equations considered the case of no cavitation regime. When the cavitation phenomena developed a sudden increase of Π can be observed. As observed by Fratino (2000), in the range of no cavitation regime, Π highlights dependence with *Re* if this parameter decreases below a threshold value. To model this dependence the Author proposes the following equation:

$$\Pi^* = \frac{A}{Re}+B\cdot\Pi \qquad (6)$$

where A and B are two constants, to be experimentally evaluated, which depend on the geometric characteristics of the device.

None of mentioned formulas can be apply in cavitation condition, where the link between pressure force and velocity square changes. This trend is highlighted in Figure 1, where the square root of pressure loss and discharge are shown.

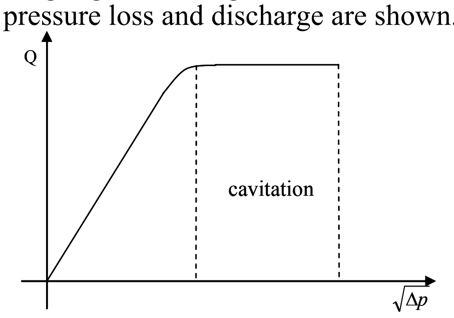

Figure 1: *Discharge versus pressure loss*

The cavitation regime can be characterized by the following parameter:

$$\sigma = \frac{P_u - P_{vap}}{P_u - P_d} \qquad (7)$$

According with ANSI-ISA standards (ISA-RP75.23-1995), σ can be calculated using downstream pipe wall vibration or sound pressure levels while flowing from fully choked flow to non-cavitating pressure drop conditions, or *vice versa*.

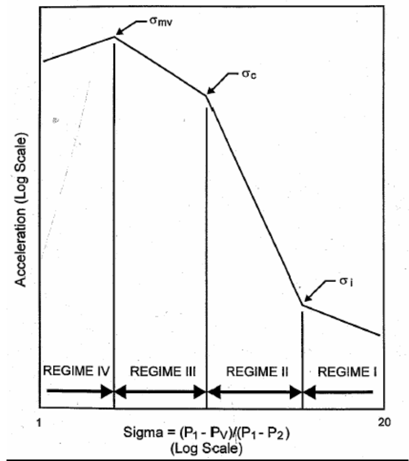

Figure 2: *Cavitation parameter plot (source: ISA-RP75.23-1995)*

Figure 2 depicts a theoretical development of experimental sigma curves. A similar behaviour can be obtained by linear interpolation of experimental data. Three intensity cavitation levels associated to different characteristics of potential danger are highlighted: the incipient cavitation limit (σ_i), the onset of cavitation, where only small vapour bubbles are formed in the flow stream; the constant cavitation (σ_c), characterized by mild and persistent popping sound and the maximum vibration cavitation (σ_{mv}), level of cavitation associated with peak vibration/sound pressure measurements.

In addiction to these levels, the chock-flow limit (σ_{ch}), beyond which the relation between discharge and head loss is no longer valid, is an important parameter to the phenomenon characterization. This limit was evaluated by comparing the behavior of the sound pressure level and the pressure loss versus σ as it is shown in *Figure 3*

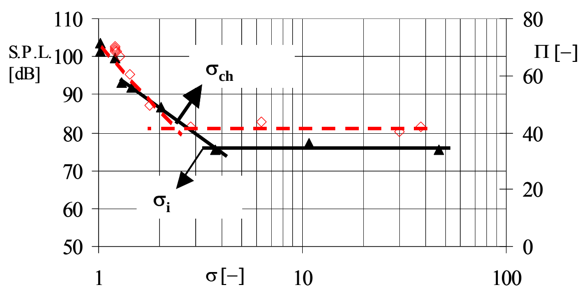

Figure 3: Sound pressure level and dissipation versus sigma (legend: ◇ Π; ▲ S.P.L)

2. EXPERIMENTAL SET-UP

The experimental tests have been performed using a pilot plant with 10" and 12" steel pipes, supplied by a pump able to guarantee pressures up to 10 bar at the reference section upstream the orifice. Control valves placed upstream and downstream the test area allowed the setting of the proper fluid-dynamic conditions for each experimental test.

The pressure has been measure with a series of absolute and differential pressure transducers in reference sections upstream and downstream the device according with the ISA-RP75.23-1995.

Flow rate has been measured by an electromagnetic flow-meter of 10”, placed upstream the test section. During the tests, temperature of the fluid has been measured in order to monitoring values of density, viscosity and vapour pressure of the fluid. Moreover, for the characterization of the cavitation regime vibration and sound pressure have been measured by mean a PCB accelerometer and a sound level meter.

Table 1 reports the several orifices tested in this work. The orifices tested differing in: geometry of the hole, sharp edge and rounded with 0.3X45° trim; thickness of the orifice; diameter of the holes. This in order to obtain specific values of the dimensionless parameters β and s/d_h. Moreover for same orifices a different distribution of the holes has been considered.

Table 1 reports also the single hole device, according to the ISA-RP75.23-1995, used to check the reliability of the whole experimental set-up.

The tests have been performed maintaining constant pressure at the upstream reference section, and decreasing the downstream pressure, in order to increase the Reynolds number and to display the cavitation phenomena. This choice has been done taking in account the characteristics of the pilot plant according with the independence of the cavitation from pressure scale effects (Fratino 2000).

3. RESULTS AND DISCUSSION

As stated in § 2, the overall behaviour of devices can be represented by dimensionless parameters Π, σ_i, σ_{mv} and σ_{ch}. A list of the numerical values obtained is reported in Table 2. Reported values of Π are calculated as the mean value within the range where no dependence of Π on *Re* was observed. Moreover, the σ values have been calculated following the *ISA-RP75.23-1995*.

Figure 4 displays dissipation trend in the analysed range of Reynolds. The results highlight tree different zones: first, for lower Reynolds

ID	n	d_h	β	s	s/d_h
6569*	52	7.6	0.72	7.6	1
7129	52	7.6	0.72	7.6	1
7078	13	8.4	0.4	6.1	0.73
7131	13	8.4	0.4	6.1	0.73
7132	13	10.7	0.51	7.8	0.73
7077	26	7.6	0.51	7.6	1
7128	26	6.0	0.4	6	1
7078*	13	8.4	0.4	6.1	0.73
7132*	13	10.7	0.51	7.8	0.73
7131*	13	8.4	0.4	6.1	0.73
7077*	26	7.6	0.51	7.6	1
7128*	26	6.0	0.4	6	1
6133	1	38.96	0.51	12.7	0.33

Table 1: Resistors dimensions (ID have rounded edge 0.3x45°)*

ID	P_u (bar)	Π	σ_i	σ_{mv}	σ_{ch}
6569*	1 - 2	1.7	9	1.02	4
7129	1 - 2	2.2	7	1.02	4
7078*	2 - 3	36.5	4	1.01	2.5
7078	1.5 - 3	42	4	1.02	2.5
7131*	2.8 - 3.8	36.5	2.5	1.01	2.5
7131	2.5 - 4	39	3	1.05	2.5
7128*	2.9 - 3.7	34	3	1.04	2
7128	1.5 - 3	35.5	4.5	1.02	2.5
7132*	2.5 - 3.5	13.5	4.5	1.3	2.5
7132	2.5	15.5	4.5	1.3	2.5
7077*	2.7 - 3.7	13.9	4	1.01	2.5
7077	2.5	13.9	4.5	1.3	2.5
6133	6.9	27	2.62	1.37	1.37

Table 2: Experimental results for orifices tested

number where *Re* affects Π without a unique trend, second where *Re* not influences Π and third, where Π rapidly increases without a significant increase of *Re*. The data distribution highlights the different influence of the geometrical and kinematical parameters in the three different zones. Indeed, the first zone can be identify with a value of *Re* about constant for all the conditions considered, while the range of cavitation regime (third zone) changes significantly with the different test conditions. In the first zone, we note different trend of Π changing β; for β=0.4, Π decreases with *Re*, while for β=0.72 Π increases with a reduction of *Re*. The dependence of Π with *Re* was observed also by Fratino (2000), even if, the Author observed an increase of Π reducing *Re*, for a device with β=0.4.

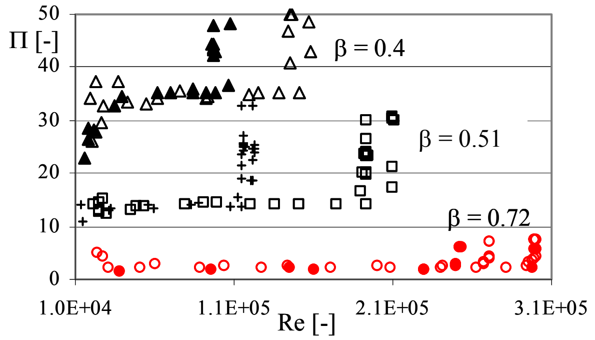

Figure 4: Dissipation versus Reynolds number (legend ▲7128 data; Δ 7128 data; + 7077 data; □ 7077* data; ● 6569 data; ○7129 data)*

In the range of no cavitation regime, the pressure losses in multihole orifices are mainly related to the contraction ratio β. In order to check the sensitiveness of the Π respected of β for our experimental data, Figure 5 reports the values of the energy loss parameter versus *Re* for all the different set-up considered in the second range before described. Results show as the influence of β is greater of the other parameters in the range of variability considered. Besides, Figure 5 highlights that the dispersion of data increases with the decreasing of β; therefore, the influence of other parameter becomes more relevant when β decreases. This behaviour is simulated by the equation 4 and 5 displayed in Figure 6 and Figure 7 respectively (where we considered $\lambda = 0.02$).

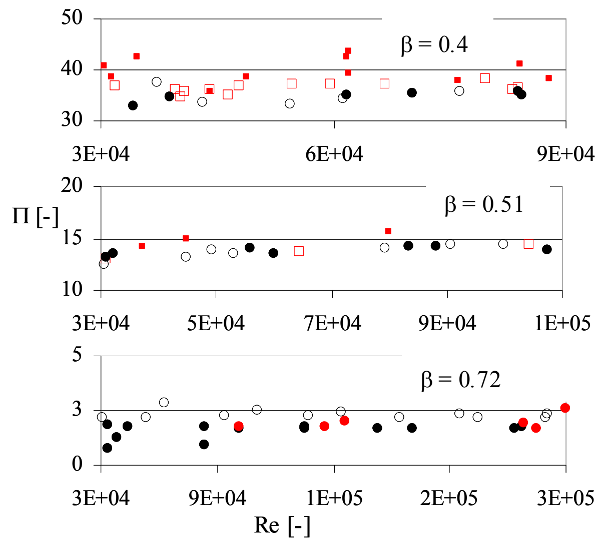

Figure 5: Dissipation versus Reynolds number (legend ■ s/dh=0.73, sharp edge; □ s/dh=0.73, rounded edge; ● s/dh=1, sharp edge; ○ s/dh=1, rounded edge)

These figures show as in the range of $0 \leq s/d_h \leq 1.3$, Π varies between 13 to 27 for β=0.51 and between 44 to 86 for β=0.4.

In Figure 6 and Figure 7 are also reported data of Fratino (2000) and data of present study. When comparable, our experimental data agree with the data of Fratino. The comparison between sharp and rounded edge evidence the low influence of the holes geometry for the two value of s/d_h considered.

The comparison between analytical formulae and experimental results highlights a good agreement between experimental data of device with 26 and 13 holes and Miller's formulae for β=0.51(Figure 6), but, for the same β, the experimental results for the single hole match Idelchik's formulae. For β=0.4 we note an overestimation of our experimental data and differences also with the multihole devices data of Fratino.

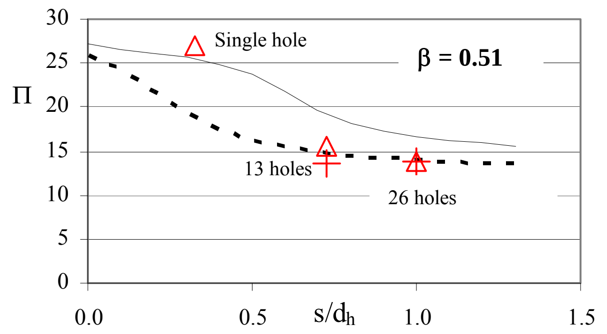

Figure 6: Comparison between experimental data and analytical formulae β=0.51 (legend: ▬ Idelchik formulae; --- Miller Formulae; + our data with rounded edge: 7132, 7077*; Δ our data with sharp edge: 7132, 7077, 6133)*

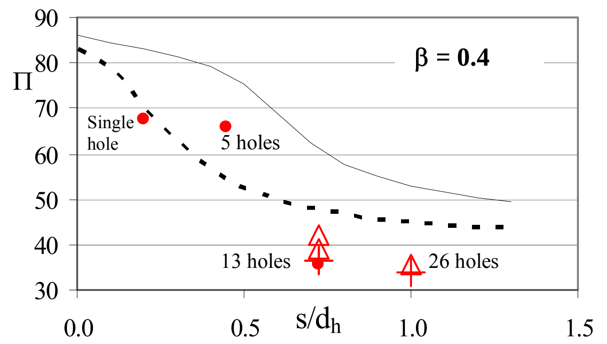

Figure 7: Comparison between experimental data and analytical formulae β=0.4 (legend: ▬ Idelchik formulae; --- Miller Formulae; ● Fratino data (2000); + our data with rounded edge: 7078, 7131*, 7128*; Δ our data with sharp edge: 7078, 7131, 7128)*

Another parameter to consider for the orifices design is the effect of distribution of holes. Within the range where Π is unaffected by the Reynolds number (second zone), Figure 7 highlights the effect of this parameter. Results show that for rounded edge, the different distribution of holes, depicted in Figure 8, has not a significant influences on dissipation, while for sharp edge device, the holes distribution change the value of Π systematically in the regne of *Re* considered.

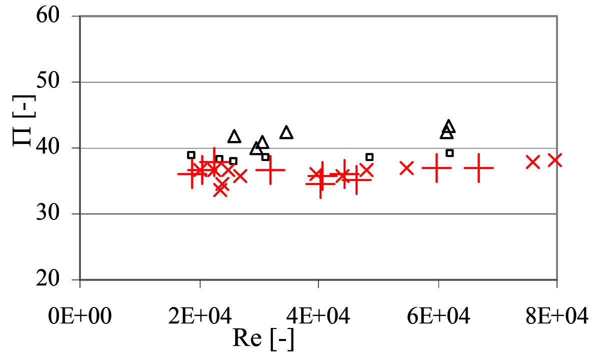

Figure 8: Dissipation, Π, versus Reynolds number for orifice 7078 and 7131 with different holes distribution (legend: + 7078 data; Δ 7078 data; X 7131* data; ▫ 7131 data)*

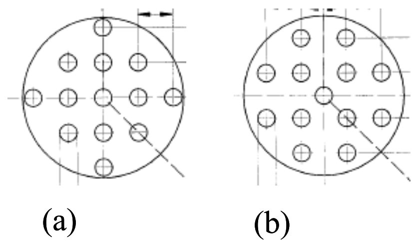

Figure 9: Different distribution of holes, (a) 7078 (b) 7131

Upon considering the third zone, tests results point out that, for the same ratio s/d_h, the β value, the distribution and the bevel of holes influence the cavitation limit, σ_i (Table 2).

To confirm the results obtained with the measure of sound pressure performed in noisy environmental, measures of acceleration have been recorded. For example, Figure 10 reports the comparison between experimental data of noise and acceleration for 26 holes device. These results highlight that the two measurement bring to the same limits of cavitation, even if limit of cavitation is determined with a linear interpolation of data (ISA-RP75.23-1995). This method could be affected by significant uncertainties depending on the number of experimental data acquired and on their distribution.

Figure 11 displays the test results of two devices of 26 holes; they have same ratio s/d_h equal to 1, but different β parameter obtained changing diameter and thickness of holes (β=0.4 for 7128 and β=0.51 for 7077). Results show the trend of sound pressure level (S.P.L.) versus sigma and the interpolation of data highlights a reduction of incipient limit of cavitation for the device with β equal to 0.4. The same result has been obtained for 13 holes device with s/d_h equal to 0.73 (Figure 12).

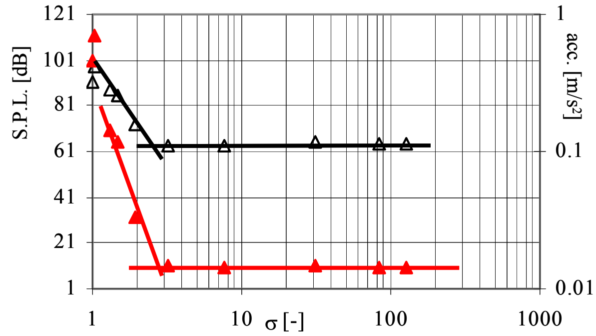

Figure 10: Sound pressure level and acceleration versus sigma for rounded edge (legend: ▲ 7128 acceleration data; Δ 7128* S.P.L. data)*

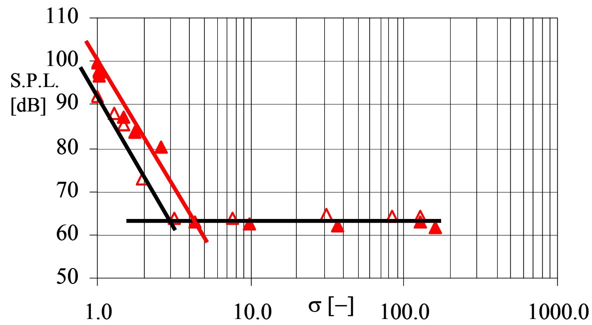

Figure 11: Sound pressure level versus sigma for rounded edge (legend: ▲7077 data; Δ7128* data)*

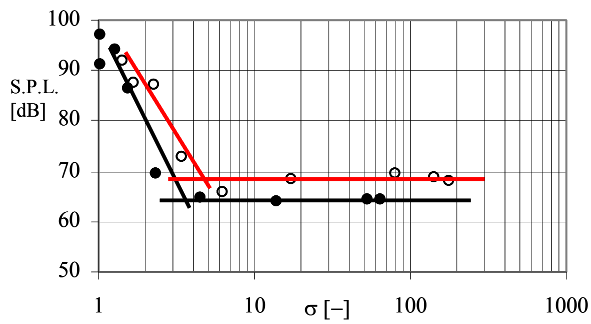

Figure 12: Sound pressure level versus sigma for rounded edge (legend: ●7131 data; ○ 7132* data)*

In Figure 13 the trend of sound pressure level is shown for two devices having different holes distribution. They have different values of incipient cavitation limits and the resistor with greater number of holes near the wall of pipe (7131*), have a lower value of incipient cavitation.

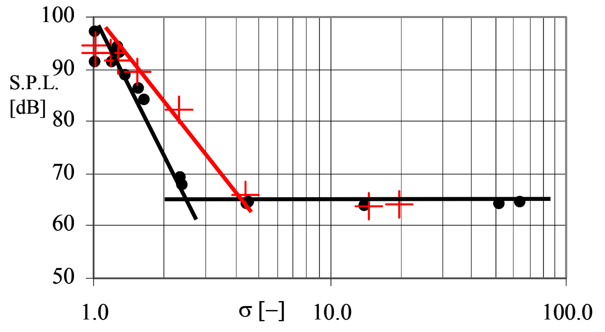

Figure 13: Sound pressure level versus sigma (legend: + 7078 data; ● 7131* data)*

The effects of the geometrical characteristic of the considered devices are negligible for the achievement of the level of maximum vibration σ_{mv} (Table 2) while we observe a significant influence of β in the achievement of the chock flow limit only for the case of β=0.72.

4. CONCLUSION

In this work the dissipation and cavitation efficiency of multihole orifices has been studied analysing the effect of different parameter involved in the process, for example contraction ratio, ratio between thickness and diameter of hole, distribution and bevel (rounded and sharp) of holes. Besides, starting from observations found in literature, a wide Reynolds range has been considered to deepen the influence of *Re* on dissipation.

In the range where *Re* not affects the process of dissipation and in fully turbulent condition, contraction ratio β is certainly the main parameter influencing the phenomenon. A reduction in β value implies an increase in dissipation efficiency decreasing, at the same time, the incipient cavitation limit and therefore, the risk of cavitation. Moreover, the effect of changing other parameters becomes more relevant for low β value.

Another important parameter is the ratio s/d_h; in fact, it, modifying the re-attachment of flow, reduces the energy loss and influences the cavitation behaviour. We have considered value of s/d_h equal to 0.33, 0.73 and 1; for these last cases, dissipation, for the same β is lower than the value recorded for 0.33 (single hole).

None of the parameters analysed influences in a notable way the maximum vibration, while the chock flow limit seems affected by β.

The comparison with analytical formulae has highlighted the necessity to revise the type of dependence from main parameters and to increase the parameters involved in the process.

The first series of experimental results here presented highlight that it is necessary a widespread experimental campaign to deepen the knowledge on the effect of the geometrical characteristic of the orifices to provide a more proper use of these devices.

5. ACKNOWLEDGMENT

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