INFLUENCE OF THE GEOMETRICAL AND OPERATIONAL PARAMETERS ON THE MIXING POINT PRESSURE IN Y-JET ATOMIZERS

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Abstract*. In this research work, the effects of the operational and geometrical parameters on the mixing point pressure in Y-jet atomizers were studied using an experimental apparatus working with air and water. The results show that the mixing point pressure is very dependent on the diameter ratio of the mixing duct and the air port and the water supply pressure ratio. A correlation to predict the mixing point pressure was developed and showed a good agreement with the experimental data. With this correlation it is possible to predict the occurrence of the critical condition for the air flow at the exit of the its port.*

Keywords: *Y-jet atomizers, Two-phase flow, Air-water, Geometric study*

1. INTRODUCTION

Y-jet atomizers are widely used in Brazil to atomize heavy-oils. One of the main reasons for their utilization is concerned to their efficiency. It permits a closer contact between the fuel and the auxiliary fluid to end by generating small drop diameter in the spray [Lefebvre (1980)]. Another characteristic of these atomizers is their low consumption of auxiliary fluid to obtain a good spray quality regarding the drop size distribution and the mean diameter [Andreussi et al. (1992)].

A great number of studies focusing on these atomizers have been carried out to determine the influence of geometrical and operational parameters in regard to the quality of the sprays generated by them. The most important works so far are: (1) Mullinger & Chigier (1974) reported an extensive parametric study and proposed some design criteria for these nozzles; (2) Andreussi *et al.* (1992), based in a semi-empirical model for the flow inside these Y-jet atomizers, were able to predict the pressure drop inside the nozzles and also the mean drop diameter in the spray through the use of one correlation with Weber and Ohnesorge numbers, based on the flow inside the atomizers; (3) Song & Lee (1994) studied the influence of mixing duct length on the internal flow characteristics and on the spray quality. They also developed one correlation using the Weber number, based on the flow inside the atomizer; (4) Andreussi *et al.* (1994) determined how the symmetry and the liquid film thickness inside the mixing duct influence spray characteristics externally to the nozzle, showing a close connection between both flows; and (5) Song & Lee (1996) made a photographic study of the flow patterns inside and outside the Y-jet atomizers and were able to determine the main mechanisms involved in the fuel atomization.

In order to study and design Y-jet atomizers, it is important to know the flow behavior in the mixing duct. Particularly, the information about the flow at the mixing point is very important to yield hypothesis that are single and accurate. One of the most important information is the knowledge of the mixing point pressure (P_M). Working with air and water, Song & Lee (1994) studied the influence of the mixing duct length and the air liquid ratio (*ALR*) on the mixing point pressure. By using an experimental apparatus specially constructed [Pacifico (2000)], this research aims to study how the other geometrical parameters, like the diameter ratio of the mixing duct and the air port and water supply pressure ratio, influence the mixing point pressure.

2. EXPERIMENTAL APPARATUS

Figure 1 shows, in a schematic drawing, the experimental apparatus used. Air and water were the working fluids. Air and water mass flow rates (W_a and W_c, respectively) were measured by corner tap orifice plates according to BSI 1042 (1989). Through the frequency control of the pump's driving electric motor and by adjusting the two valves upstream the pump, it was possible to obtain the desired levels of water mass flow rate and pressure supply (P_c). The air mass flow rate was obtained from its pressure supply (P_{a0}) –there was an electronic adjustment in the compressor– and the pressure drop of the air line. P_c, P_{a0} and the mixing point pressure (P_M) of the Y-jet atomizers were measured by piezo-resistive transducers. Finally, in figure 1, T_{a0} and T_c represent the air and the water supply temperatures, respectively. All the experiments were conducted at room temperature. P_{a0} ranged from 4.7 to 11.7 bar and P_c from 1.5 to 17 bar. The spray was discharged in the laboratorial environment, i.e., at atmospheric pressure.

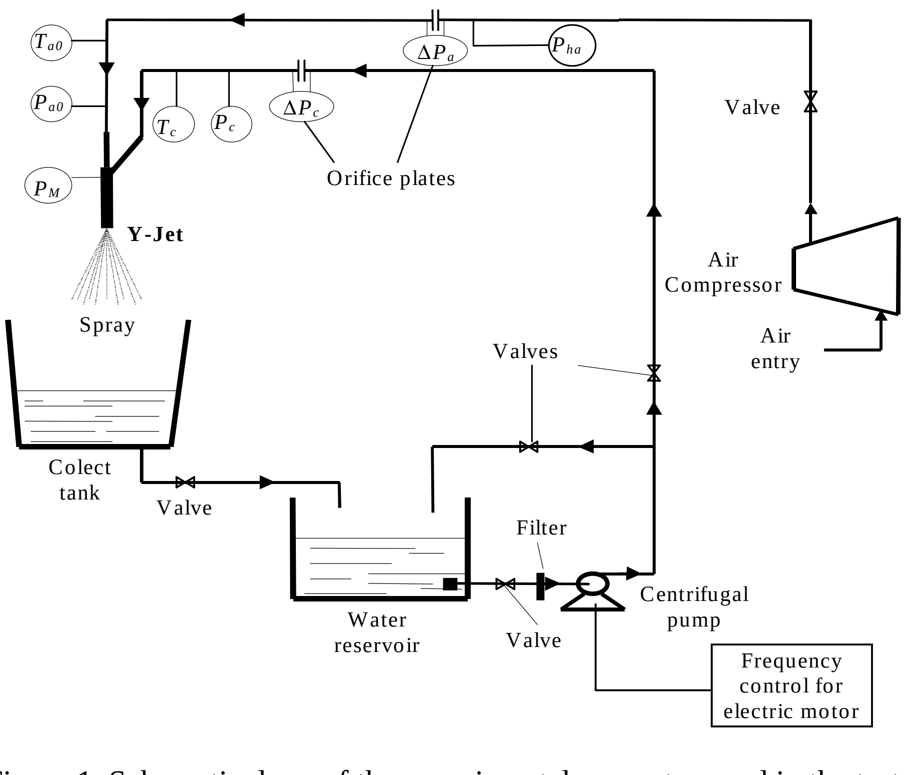


Figure 1. Schematic draw of the experimental apparatus used in the tests.

In order to allow parametric analysis, seven Y-jet atomizers were constructed according to Mullinger and Chigier's design criteria. The tested nozzles can be seen in the figure 2 in an schematic drawing. Table 1 shows the main values of the geometrical parameters used.

The atomizers were manufactured using a 3:1 scale in order to allow easier access to the pressure and temperature sensors, without perturbing the flow. To maintain a comparison basis relative to the air (G_a) and the water (G_c) fluid mass velocities generally used in Y-jet atomizers, W_a and W_c, ranged as follows: 40 < W_a < 320 kg/h and 240 < W_c < 2600 kg/h.

The main geometrical parameters studied were: the water port to the mixing duct entry angle (θ); the ratio between the mixing duct length and diameter (l_m/d_m); and the ratio between the mixing duct and the air port diameters (d_m/d_a) that includes the effects of the air flow expansion from the air port to the mixing duct. The following set of atomizers were used for each parametric study: nozzles # 2, # 4 and # 5 for θ; nozzles # 2, # 6 and # 7 for l_m/d_m; and nozzles # 1, # 2 and # 3 for d_m/d_a. These values are shown in table 1 for each nozzle.

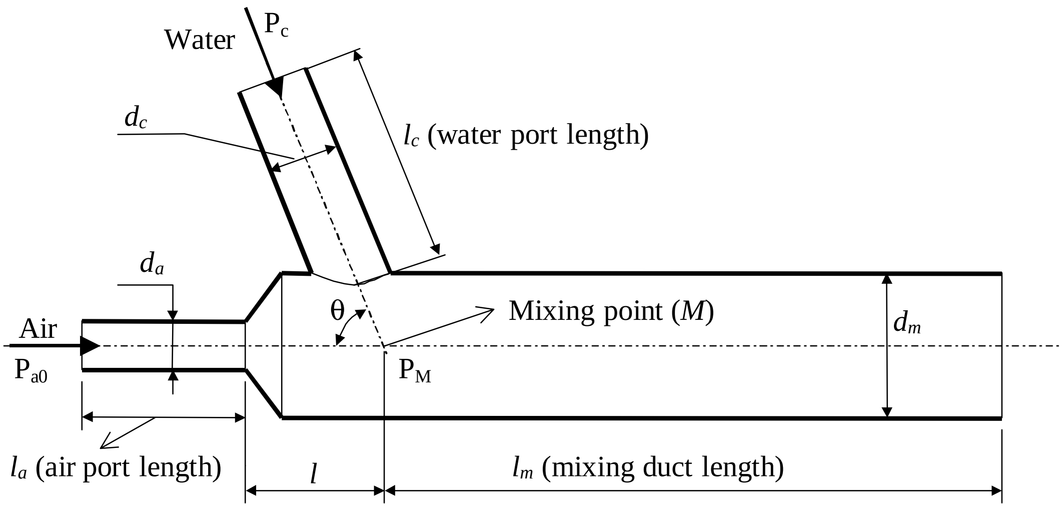


Figure 2. Schematic draw of one generic y-jet atomizer used in this work.

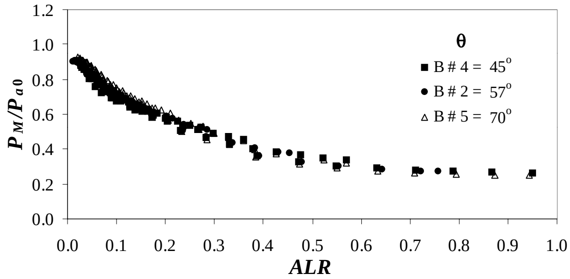
Table 1. Geometrical values for the parameters in the figure 2.

Atomizer	l_a **[mm]**	l_c **[mm]**	l **[mm]**	l_m **[mm]**	d_a **[mm]**	d_c **[mm]**	d_m **[mm]**	θ	l_m/d_m	d_m/d_a
# 1	30	40	13.5	50	5.5	8	10	57°	5.00	1.82
# 2	30	50	14.0	50	6.0	8	10	57°	5.00	1.67
# 3	30	50	14.7	50	6.0	8	12	57°	4.17	2.00
# 4	30	50	16.7	50	6.0	8	10	45°	5.00	1.67
# 5	30	50	12.1	50	6.0	8	10	70°	5.00	1.67
# 6	30	50	14.0	35	6.0	8	10	57°	3.50	1.67
# 7	30	50	14.0	100	6.0	8	10	57°	10.00	1.67

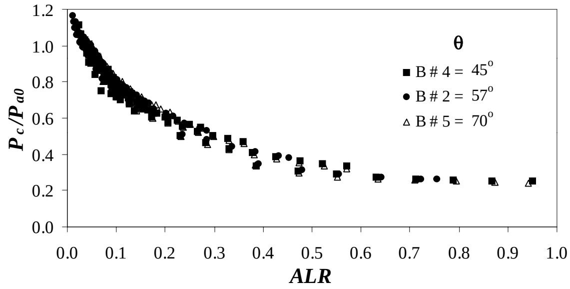
3. RESULTS AND DISCUSSION

The results for the P_M/P_{a0} and Pc/P_{a0} ratios as function of the geometrical relationship of nozzles # 1 to # 7 and the air liquid ratio, ALR (= W_a/W_c), are shown in figure 3.

In qualitative terms, all results are similar, i.e., P_M and P_c decreases with the increment of ALR. This behavior occurs because the increment of ALR is the result of the increment of W_a or the decrement of W_c, which induces the air flow momentum to have a larger influence on the mixing process, and particularly on the mixing point pressure. On the other hand, as the water flow determines the back pressure for the air expansion, the value of the ratio P_c/P_{a0} is also important. This behavior is intrinsic to any compressible fluid expansion and yields to the conclusion that P_M is controlled by the water flow rate in the mixing point.



(a)



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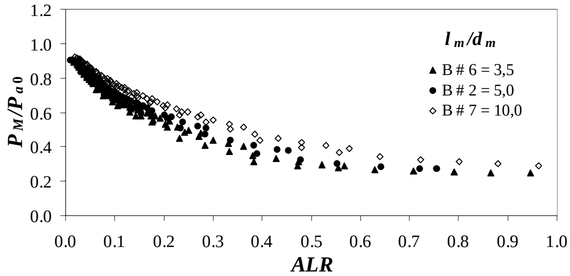
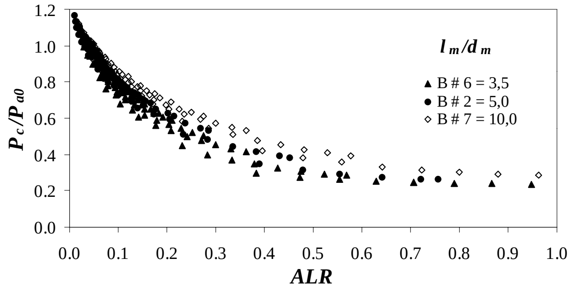


(c)



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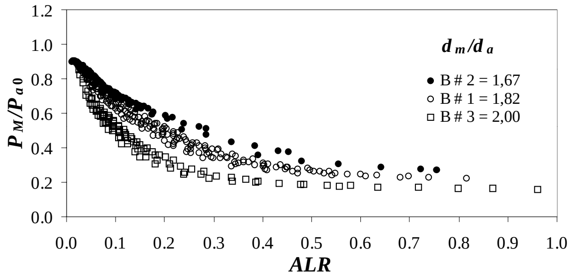
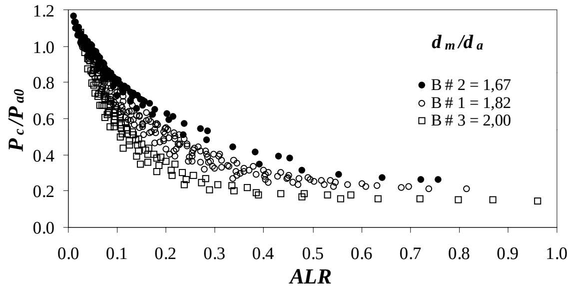


(e)



(f)

Figure 3. Influence of geometrical parameters on the P_M/P_{a0} and P_c/P_{a0} ratios as a function of *ALR*.

In figure 3, it can also be seen that there are values for P_M/P_{a0} smaller than 0.5283 (for $ALR > 0.25$), in all the cases studied. The hypothesis here is that the flow from air port to the mixing point is single phase (air only) with $\gamma = 1.4$, where γ is the ratio of specific heats. This critical condition happens because of the air port geometry and the air flow discharge in the mixing duct. These nozzles in Y-jet atomizer are similar to a converging–diverging nozzle, where the air port (d_a) acts as a nozzle throat and the mixing point pressure (P_M) as the back pressure in the diverging passage (controlled by the water flow in this region). More details about the critical air phenomenon can be found in Pacifico (2000).

Figures 3a and 3b show, respectively, the influence of θ on P_M/P_{a0} and on P_c/P_{a0} as a function of *ALR*. There is virtually no difference among the results, concluding that θ doesn't exert significant influence on the mixing point pressure.

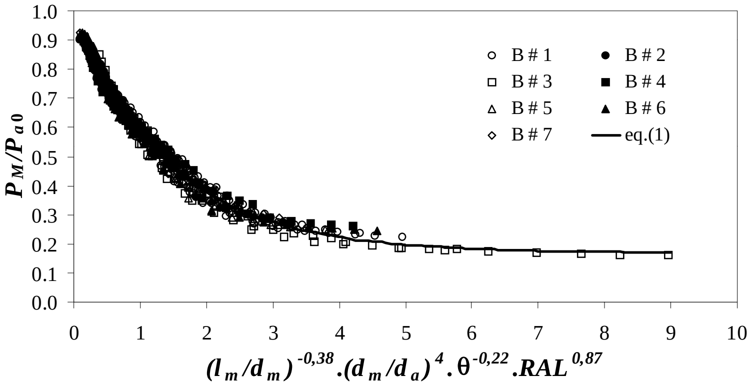
Figures 3c and 3d show respectively the influence of l_m/d_m on P_M/P_{a0} and P_c/P_{a0} as a function of *ALR*. The results indicated that P_c, and consequently P_M, increases with the raise of l_m/d_m since the pressure drop inside the mixing duct is smoother for larger values of l_m. Thus, the environmental pressure being the same for the three nozzles (i.e., the atmospheric pressure), Y-jet's with higher l_m have also higher values for P_M. Pacifico (2000) shows a detailed study about the pressure distribution inside the mixing duct for all Y-jet atomizers tested.

Finally, it has been confirmed that the influence of d_m/d_a on P_M and P_c is the most significant of all the geometrical relations studied here. These results can be seen in figures 3e and 3f. Higher values of d_m/d_a produces higher values of the pressure drop between the stagnation pressure in the air port (P_{a0}) and the static pressure in the mixing point (P_M). Particularly, in the range $0.1 < ALR < 0.4$, the influence of d_m/d_a is more remarkable, indicating that the air pressure drop in this region is larger when d_m/d_a is incremented.

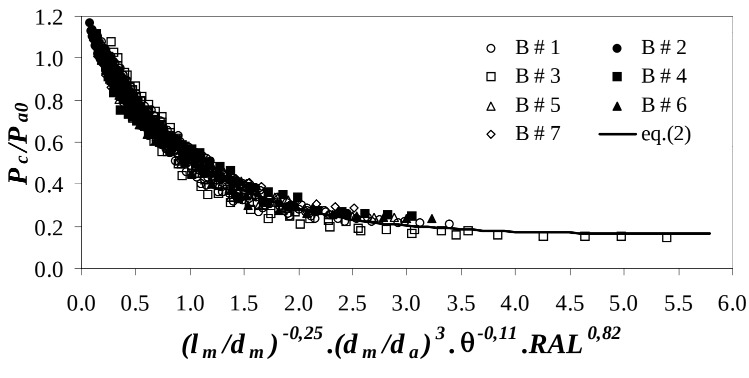
In order to show in a single curve the influence of all parameters analyzed in figure 3, two correlations for the P_M/P_{a0} and P_c/P_{a0} ratios were proposed. Figure 4 shows these correlations, along with the results obtained for nozzles # 1 to # 7. The correlations are,

$$\frac{P_M}{P_{a0}} = 0.169 + 0.81\exp\left[-0.675\left(\frac{l_m}{d_m}\right)^{-0.38}\left(\frac{d_m}{d_a}\right)^{4}\theta^{-0.22}ALR^{0.87}\right] \quad (1)$$

$$\frac{P_c}{P_{a0}} = 0.161 + 1.06\exp\left[-1.080\left(\frac{l_m}{d_m}\right)^{-0.25}\left(\frac{d_m}{d_a}\right)^{3}\theta^{-0.11}ALR^{0.82}\right] \quad (2)$$



(a)



(b)

Figure 4. Comparisons between results obtained using correlations (1) and (2) and experimental ones.

The correlations shown in Eqs. (1) and (2) are valid for the following range: 0 ≤ ALR ≤ 1; 3.5 ≤ l_m/d_m ≤ 10; 1.67 ≤ d_m/d_a ≤ 2; and $45^o < \theta < 70^o$. In the correlation, θ must be given in radians ($\pi/4 < \theta < 7\pi/18$). As it can be seen in figure 4, there is a good agreement between the experimental points and the correlations given by Eqs. (1) e (2).

An important design parameter is the condition for critical air flow. For the present case P_M/P_{a0} < 0.5283 (critical condition) is obtained when $(l_m/d_m)^{-0.38}(d_m/d_a)^4\theta^{-0.22}ALR^{0.87} > 1.2$.

Figure 5 shows the relation the P_M/P_c ratio as a function to *ALR*, for the three geometric relationships studied and for the two values of P_{a0}: 6.8 bar and 8.8 bar.

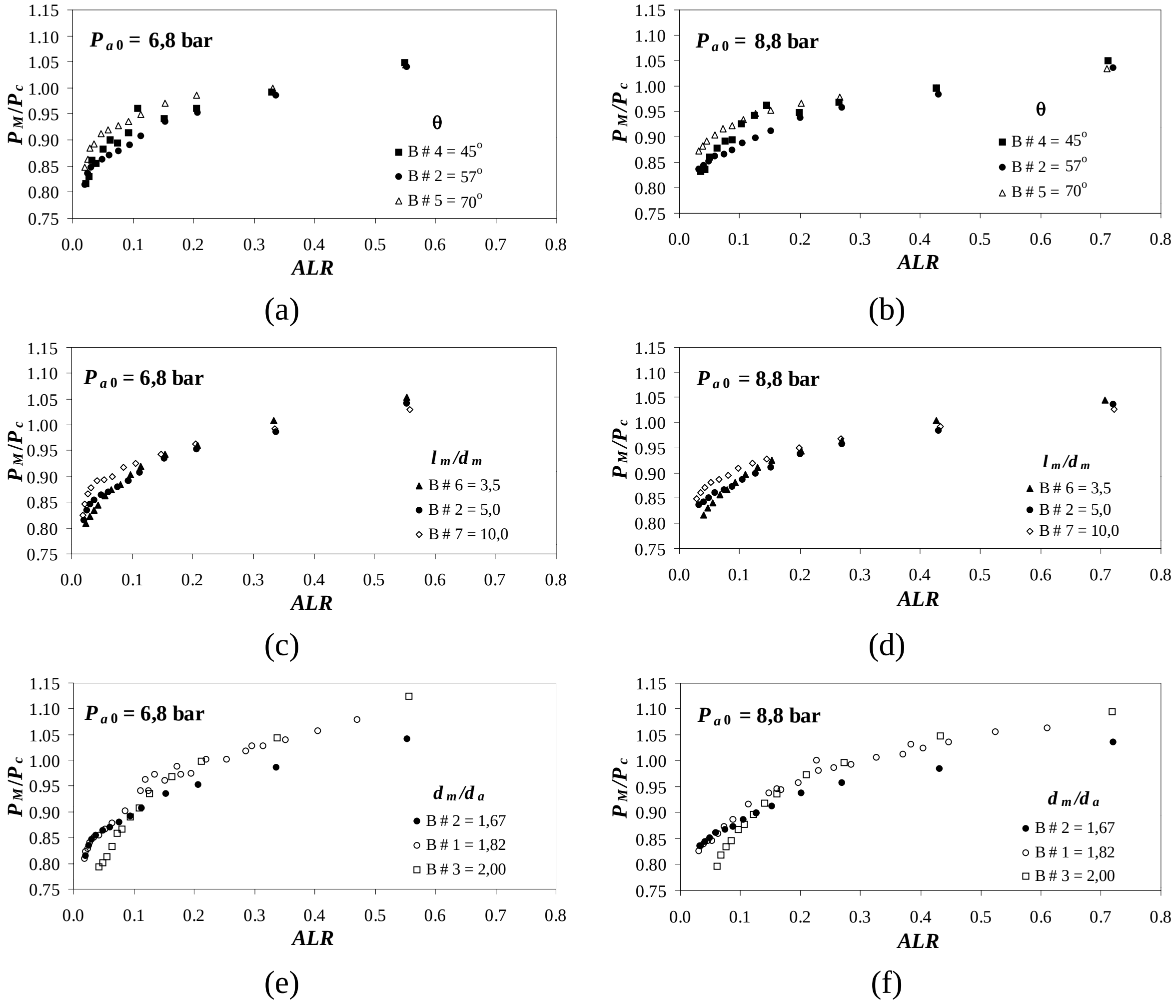


Figure 5. Influence of geometrical parameters on the P_M/P_c ratio as a function of *ALR* for two values of P_{a0}: 6.8 bar and 8.8 bar.

From figure 5, it can be seen that the increasing of P_M/P_c is associated with the increasing in *ALR*, which is an opposite behavior compared to P_M/P_{a0} (figure 3). For low values of *ALR*, the water flow lateral momentum is prevalent to the air flow axial momentum and there is a higher pressure drop in the water port to the mixing point relative to the natural water discharge. For high values of *ALR*, the behavior is the opposite, reaching to $ALR \cong 0.5$ with $P_{a0} = 6.8$ bar and $ALR \cong 0.7$ with $P_{a0} = 8.8$ bar, for $P_M/P_c > 1$. For all the *ALR* range shown in the graphics, the mixing point flow is two-phase and thus the behavior of P_M/P_{a0} and P_M/P_c is not obvious. Both P_{a0} and P_c measurements are for single-phase flows and P_M for a two-phase flow. What happens is that, for the extreme values of *ALR*, the momentum of the prevalent phase (liquid for low values of *ALR* and gas for high values of *ALR*) is dominant over the other one. Finding $P_M/P_c > 1$ for high values of *ALR* means that, in these conditions, P_M is determined by the air expansion (in this region it was always found that $P_{a0} > P_c$).

Figures 5a and 5b show the influence of the angle θ on the P_M/P_c ratio. An irregular behavior can be seen for nozzle # 4, $\theta = 45^o$. Finally, the evolution of the P_M/P_c ratio with *ALR* for this nozzle is different from the others nozzles. It can also be observed that for *ALR* < 0.3, P_M/P_c increases with the increment of θ. When *ALR* > 0.3, the results are similar, with a lower influence of θ.

Figures 5c and 5d show the influence of l_m/d_m. The increase of *ALR* produces an inversion between the two curves of l_m/d_m (lower and higher values). In other words, for lower values of *ALR* ($W_c >> W_a$), the pressure drop for water from its port to the mixing point is higher for lower values of l_m/d_m. The opposite occurs for high values of *ALR*.

Figures 5e and 5f show how d_m/d_a influences P_M/P_c. For *ALR* < 0.1 there is virtually no difference between the behavior of nozzles # 1 e # 2. In the same range, the values of P_M/P_c is lower for the nozzle # 3 (higher d_m/d_a). For *ALR* > 0.1, the influence of the higher expansion ratio (Y-jet # 3) becomes more outstanding, yielding to higher values of P_M/P_c. In general, when there is an increase of *ALR*, the influence of d_m/d_a becomes clearer.

4. CONCLUSIONS

In this study the influence of the operational and geometric parameters on the pressure of the mixing point of Y-jet atomizers was carefully examined. Air and water were the working fluids. Water supply pressure exerts a large influence on the mixing point pressure, acting as a back pressure for the air expansion, if one considers a converging–diverging nozzle analogy. The ratio between the mixing duct and the air port diameters was the main geometric parameter that regulates the mixing duct pressure. The correlation developed to foresee the mixing point pressure [Eq. (1)] as a function of operational and geometric parameters studied, showed to agree well with the experimental results.

An important design parameter is the condition for critical air flow. For the present case $P_M/P_{a0} < 0.5283$ (critical condition) is obtained when $(l_m/d_m)^{-0.38}(d_m/d_a)^4\theta^{-0.22}ALR^{0.87} > 1.2$.

5. ACKNOWLEDGMENT

The authors would like to express their appreciation to the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) for its financial support for this research work (97/04542-8).

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