Ref Proc 1997/8774-0 Relatório Científico, ANEXO 1, PAPER 1/2.

THE SPIDER-JET ATOMIZER: AN EVOLUTION OF THE Y - JET ATOMIZER CONCEPT

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Keywords: Atomizers, Y-Jet Atomizers, Liquid Films, Droplets and Sprays
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ABSTRACT

This work discusses a new type of a high capacity atomizer with a wide range of operation that is an off-spring of the well known Y-Jet atomizer . It is a fact that Y-Jet atomizers have a good performance but become mechanically more complex when one needs to operate with higher flow rates. It establishes the design rules for this atomizer, estimates the mean liquid film thickness at the injector exit (which is more uniform than the one generated by the equivalent Y-Jet atomizer) and calculates the Sauter Mean Diameter of the droplets generated by this device, using an extension of a theoretical formula for the SMD of the droplets generated by a Y-Jet atomizer, which compared well with experimental results..

1. INTRODUCTION

Internal mixing twin fluid air blast (Y-jet) atomizers, in which liquid is injected into a mixing chamber with compressed air or steam, are extensively used in industry. The principles of functioning of this type of atomizer were described in an experimental paper by Mullinger and Chigier [1]. A theoretical formula for the Sauter Mean Diameter (SMD) of the droplets generated by a Y-Jet atomizer, which compared well with experimental results, was recently derived by Couto et al [2], using an analogy based upon the hypothesis of Dombrowski and Johns [3] regarding the behavior of a planar disintegrating liquid sheet, who showed that the main source of instabilities that causes sheet disintegration into droplets is related to the interaction between the sheet and the surrounding gaseous medium, when disturbances interact with the sheet. Disintegration occurs when the wave amplitude of the disturbance attains a critical value and the sheet breaks up into fragments which form unstable ligaments that contract under the action of surface tension, forming droplets. Dombrowski and Johns [3] derived an equation for the droplet size based on the concept of a planar liquid sheet and their theoretical values compared well with experimental results. Couto et al [4] applied these ideas to the pressure swirl atomizer assuming that a conical sheet formed from the atomizer final discharge orifice possesses a much larger rupture radius than the sheet thickness and that the wavelength of the ripples formed in the liquid film grows until their amplitude equals the ligament radius, so that one droplet is produced per wavelength [3]. Once the conical sheet is established, the amplitude of the ripples away from the injector is assumed to be much smaller than the cone diameter so that disturbances "see" the conical sheet as a

plane one. With these hypotheses, it was possible to apply the theory developed for thin planar liquid sheets to conical thin sheets.
The fact is that Y-Jet atomizers have a good performance but become mechanically more complex when one needs to operate with higher flow rates, for then one must associate several Y-Jet units within a single injection head.
This work discusses a new type of a high capacity atomizer with a wide range of operation that is an off-spring of the well known Y-Jet atomizer which has a good performance but becomes mechanically more complex when one needs to operate with higher flow rates for then one must associate several Y-Jet units within a single injection head. This is not so with the Spider-Jet atomizer concept (Figure 1) which possesses all the outstanding features of the Y-Jet atomizer while being a mechanically simple device of easy design and operation. Besides, its design procedure is quite similar to the one normally used for Y-Jet atomizers.
This paper establishes the design rules for the Spider-Jet atomizer, estimates the mean liquid film thickness at the injector exit (which is more uniform than the one generated by the equivalent Y-Jet atomizer) and describes the calculation of the Sauter Mean Diameter (SMD) of the droplets generated by this atomizer.

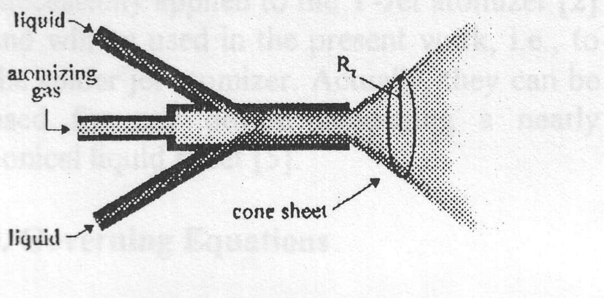

Figure 1 a - Schematic of a Spider Jet Atomizer and its assumed conical sheet (n=2).

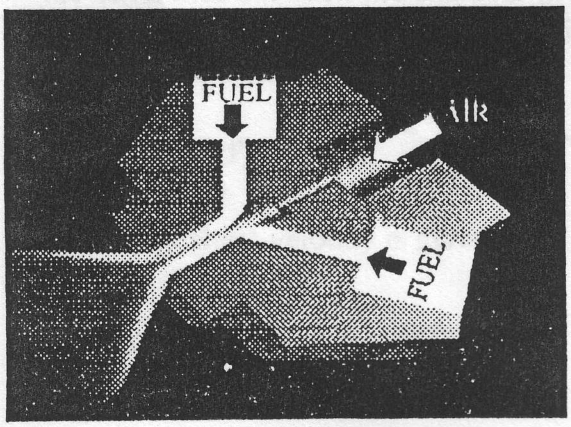

Figure 1 b – Spider Jet injection head.

2. Problem Description

Figure 1 shows a schematic of a typical Spider Airblast Atomizer. The liquid upon entering the mixing chamber through the existing channels is pushed against its walls by the incoming pressurized atomizing gas generating a liquid film. This liquid film is then ejected from the discharge orifice as a nearly conical sheet which disintegrates into fragments which form unstable ligaments that contract under the action of surface tension, forming droplets. Once the film thickness is estimated then, the SMD of these droplets is calculated using an analogy based upon the hypothesis of Dombrowski and Johns [3], regarding the behavior of a planar disintegrating liquid sheet, who showed that the main source of instabilities that causes sheet disintegration into droplets is related to the interaction between the sheet and the surrounding gaseous medium, when disturbances interact with the sheet. They derived an equation for the droplet size based on the concept of a planar liquid sheet and their theoretical values compared well with experimental results.

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If one assumes that the conical liquid sheet formed from the atomizer discharge orifice possesses a much larger rupture radius than the sheet thickness and that the wavelength of the ripples formed in the liquid film grows until their amplitude equals the ligament radius, so that one droplet is produced per wavelength [3]. Once the thin conical sheet is established, the amplitude of the ripples away from the injector is assumed to be much smaller than the cone diameter so that disturbances "see" the conical sheet as a plane one. These ideas have been successfully applied to the Y-Jet atomizer [2] and will be used in the present work, i.e., to the spider jet atomizer. Actually, they can be used for any device generating a nearly conical liquid sheet [5].

3. Governing Equations

As the atomizing gas and the liquid are discharged together in the surrounding medium the main parameter in this process is the difference between the chamber pressure, P_c, and the ambient pressure, P_s, which are the same for both fluids, i.e.,

$$\Delta P_l = \Delta P_{ar} = P_c - P_s \tag{1}$$

The liquid sheet velocity is given by:

$$U_f = C_d\left(\frac{2\Delta P_l}{\rho_l}\right) \tag{2}$$

where C_d is the discharge coefficient and ρ_l is the liquid density.

The continuity equation for incompressible fluids yields

$$\dot{m}_f = n.\dot{m}_{fi}$$

where m_f is the total liquid mass flow rate, written as

$$\dot{m}_f = \rho_l U_f \frac{\pi}{4}\left[D_o^2 - (D_o - 2h_0)^2\right] \tag{3}$$

and m_f is the liquid mass flow rate through one of the n existing feeding channels and where $\frac{\pi}{4}\left[D_o^2 - (D_o - 2h_0)^2\right]$ is the area of the ring formed by the liquid film at the injector exit, D_o is the chamber exit diameter, h_0 is the liquid film thickness. Then:

$$h_0 = \frac{D_0 - \left(D_0^2 - \frac{4n\dot{m}_{fi}}{\pi\rho_l U_f}\right)^{\frac{1}{2}}}{2} \tag{4}$$

Dombrowski and Johns [3], derived the following expression for estimating the diameter of the ligaments, d_l, formed upon the breaking of a liquid film:

$$d_l = 2\left(\frac{4}{3f}\right)^{\frac{1}{3}}\left(\frac{K^2\sigma^2}{\rho_a\rho_l U_i^2}\right)^{\frac{1}{6}}\left[1+2{,}6\mu_l\sqrt{\frac{K\rho_a^4U_i^8}{6f\rho_l^2\sigma^5}}\right] \quad (5)$$

Choosing f=12 as done by Dombrowski and Johns [3] , one obtains

$$d_l = 0{,}9615\left(\frac{K^2\sigma^2}{\rho_a\rho_l U_i^2}\right)^{\frac{1}{6}}\left[1+2{,}6\mu_l\sqrt{\frac{K\rho_a^4U_i^8}{72\rho_l^2\sigma^5}}\right]^{\frac{1}{5}} \quad (6)$$

where σ [dyn/cm] is the liquid surface tension, μ_l [cp] is the liquid dynamic viscosity, ρ_a [g/cm³] is the density of the surrounding medium , ρ_l[g/cm³] is the density of the liquid, K is the "nozzle parameter" which those authors calculated for fan-spray atomizers only and U_i [cm/s] is a velocity term which, in a general case, can be seen to be composed of three components: two of them relative to the air flowing on both sides of the liquid sheet , the third one being the velocity of the sheet itself [6]. Therefore, one may choose a mean value for the velocity field as

$$U_i = \left[\frac{1}{3}\left[U_f^2 + (U_{1a}-U_f)^2 + (U_{2a}-U_f)^2\right]\right]^{\frac{1}{2}} \quad (7)$$

where U_{1a} and U_{2a} are the air velocities on either side of the sheet and U_f is the sheet velocity.

As the air velocity outside the liquid sheet is taken to be zero in this atomizer, one may write:

$$U_i = \left[\frac{1}{3}\left[2U_f^2 + (U_{1a}-U_f)^2\right]\right]^{\frac{1}{2}} \quad (8)$$

It can be shown [4] that the nozzle parameter, K, for atomizers which generate nearly conical sheets is given by:

$$K = \left(\frac{h_0^2\cos^3\theta}{U_f}\right) \quad (9)$$

where θ is the half cone angle formed by the liquid sheet upon leaving the atomizer.

Using equations (8) and (9) into equation (6), one obtains:

$$d_l = 0{,}9615\left(\frac{h_0^4\sigma^2\cos^6\theta}{\rho_a\rho_l U_f^2U_i^2}\right)^{\frac{1}{6}}\left[1+2{,}6\mu_l\sqrt{\frac{h_0^2\cos^3\theta\rho_a^4U_i^8}{72U_f\rho_l^2\sigma^5}}\right]^{\frac{1}{5}} \quad (10)$$

for the diameter of the ligaments which, according to Rayleigh (apud Lefebvre, [7]), will generate droplets with a Sauter Mean Diameter, SMD, of

$$SMD = 1{,}89d_l \quad (11)$$

4. Design Procedure

A schematic of the spider Jet atomizer is shown in figure1. Determination of the atomizer dimensions, basically the liquid and air injection orifices and the mixing chamber dimensions was based on Mullinger and Chigier's guidelines [1] and on the following assumptions: a) isentropic flow through the atomization air orifice, b) Mach number equal to unity at the air orifice outlet section, c) stagnation air temperature of 298 K, and d) liquid injection discharge coefficient of 0.75. At the design operation conditions, the ratio between the atomization air to the liquid flow rates was chosen to be 0.1.

Experiments with water were performed for atomization air injection pressures of 8, 15 and 25 psig, for the case where n=1, i.e., the conventional Y-Jet atomizer. In these tests, the air mass flow rate was measured with a calibrated orifice plate and the water mass flow rate with a rotameter. The following parameters were then calculated, under the assumption of isentropic flow through the air injection orifice: injection Mach number, air density and stagnation pressure and temperature in the mixing chamber. The air velocity at the end of the mixing chamber was calculated from the chamber dimensions using the calculated air density, and the ratio between the air and liquid mass flow rates.

It should be pointed out that the injection pressure of 8 psig is out of the atomizer assumed design point because 8 psig = 22,7 psia < 27,84 psia = (14.7/0.528) psia, i.e., Mach = 1 at the injection port is a value that cannot be expected for such low air diferential pressure injection, even with no liquid in the mixing chamber water

6. Conclusions

It is observed that the results obtained with the theoretical formulation derived in this work fit very well with the experimental data even for the case of n=1, i.e., for the Y-Jet atomizer as shown in

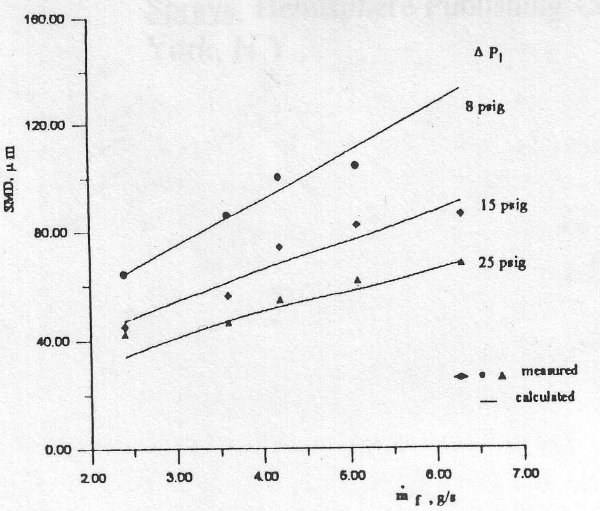

Figure2– SMD (calculated and measured) vs mass flow rate,ΔP_l = 8, 15 and 25 psig [2]

Figure 2 .As mentioned by Couto et al.[2], one of the strong features of the formulation is that it takes into account the atomizer geometrical characteristics through the nozzle parameter K. The Sauter Mean Diameter has been shown to be very sensitive to K, which by its turn, is strongly dependent on the liquid film thickness, h_0. Therefore, by measuring the droplets SMD one may conclude that the expression derived for h_0, i.e., Equation (4), is satisfactory in describing the overall phenomenon of the liquid film generation even for the case where n=1. Therefore, as the use of a larger number of liquid feed channels will certainly cause an improvement in the uniformity of the film thickness distribution pattern, one should expect the calculated model to come even closer to the experimental data, although even for the far off-design injection pressure of 8 psig, the formulation stood well compared with the experimental data .

7. Acknowledgements

The authors are indebted to Prof. M. Q. McQuay of the BYU and Mr P.T. Lacava of INPE for the release of the experimental results shown in this work.

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