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THEORY AND DESIGN TECHNIQUE FOR A SPLASH PLATE ATOMIZER

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SUMMARY

This work studies a liquid atomizer where the droplets are generated by a liquid jet impacting on a solid target (splash plate atomizer). It suggests a theoretical model by describing the droplet size distribution function allowing the calculation of its moments, one of them, the Sauter Mean Diameter which is then used to optimize the atomizer design.

INTRODUCTION

Liquid atomizers where the droplets are generated by a jet impacting a solid target (splash plate atomizers), have the convenient advantage of easy calibration, since it is simpler to adjust this set up than to do the precise alignment of a pair (or more) of impinging liquid jets. However, it is known that, while the later technique of spray generation has found wide application, the former one has a very limited use. A reason for this might be the lack of a theory to allow for proper design and optimization. This suggests a theoretical model for this kind of droplet generation device, describing the droplet size distribution function, calculating some of its moments (one of them the Sauter Mean Diameter) and then using the behavior of this parameter as a method to optimize the atomizer design.

GOVERNING EQUATIONS

It has been shown by Couto (1992) that the droplet size distribution function in a spray formed by impinging jets is given by:

$$f(\phi)=\frac{6V_o R^2 \sin\theta}{\pi . d_d^3 . (1-\cos\theta.\cos\phi)} \sqrt{1-\cos^2\theta.\sin^2\phi} \qquad (1)$$

The above equation is obtained for two identical cylindrical liquid jets of radius R, velocity V_o in a quiescent medium colliding obliquely at an angle 2θ and where ϕ is the azimuthal angle as sketched in Figure 1. In that equation d_d, the droplet diameter, can be written as (Dombrowski and Johns, 1963 and Couto and Bastos-Netto, 1991):

$$d_d = \left(\frac{3\pi}{2}\right)^{1/3} . d_L . \left(1 + \frac{3\mu}{\rho_L . \sigma . d_L}\right)^{1/6} \qquad (2)$$

where μ (cp) is the viscosity, σ (dyn.cm^{-1}) the surface tension, ρ_L (g.cm^{-3}) the liquid density and d_L (cm) is the ligament diameter given by:

$$d_L=0.9416\left(\frac{k^2 . \sigma^2}{\rho . \rho_L . U^4}\right)^{1/6}\left[1+2.60\mu\left(\frac{k . \rho^4 . U^7}{72 . \rho_L^2 . \sigma^5}\right)^{1/3}\right]^{1/5} \qquad (3)$$

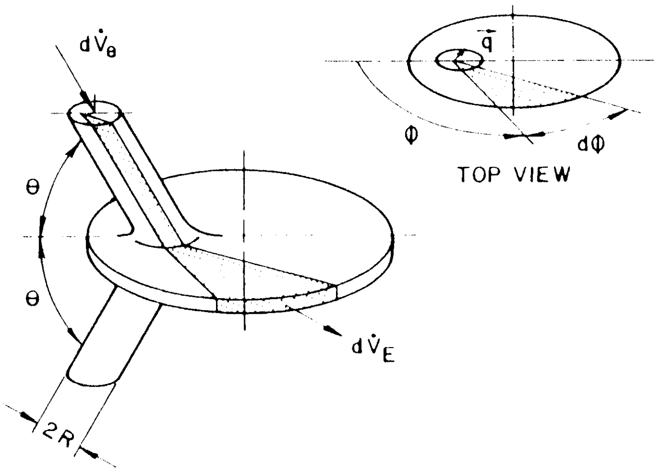

Figure 1. Sheet formed by impinging jets.

where ρ (g.cm^{-3}) is the density of the gaseous medium, U can be taken nearly equal to the jet velocity (Dombrowski and Johns, 1963) and k is written as (Couto and Bastos-Netto, 1991):

$$k = \frac{R^2 \sin^3\theta}{(1 - \cos\theta . \cos\phi)^2} \qquad (4)$$

It is known that the impinging jets generate a sheet whose symmetry plane acts as a rigid surface (Hasson and Peck, 1964). This leads us to the conclusion that a solid target can nicely simulate this rigid surface if this target is taken to be plane smooth and equal to, or slightly bigger than the impacting cross section, so to prevent the influence of surface tension and wall shear. Thus, it is straighforward the use of the above reasoning to construct the droplet size distribution function in a spray generated by a single liquid jet impacting a solid target as suggested in Figure 2. Is has been shown by Couto (1992) that the number of droplets of a given spherical volume V_d generated per second, $d\dot{n}$, between ϕ and $\phi + d\phi$, can be written as:

$$d\dot{n} = d\dot{V}_E / V_d \qquad (5)$$

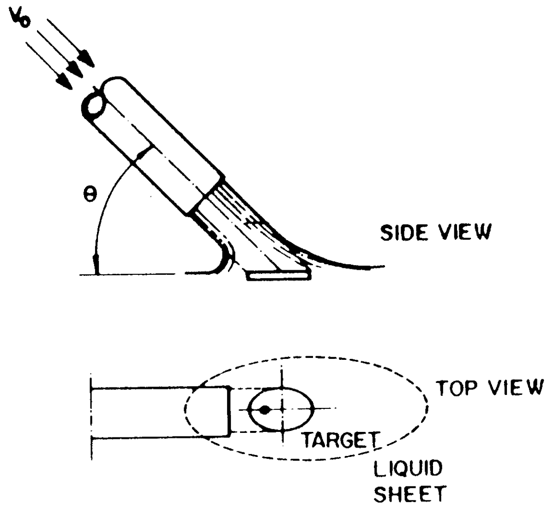

Figure 2. Schematics of an splash-plate atomizer.

where $\dot{V}_E$ is the volume flow rate streaming out the sector $d\phi$ as shown in Figure 2. Assuming as before (Couto, 1992 and Hasson and Peck, 1964) that the mass flow rate is conserved within this angular differential element, one may write:

$$d\dot{V}_E = d\dot{V}_e \qquad (6)$$

where the subscripts "E" and "e" stand for the sheet and the jet cross sections respectively. From this point on, following Couto (1992), it is easily shown that the distribution function, $f(\phi) = d\dot{n}/d\phi$, becomes for this kind of atomizer,

$$f(\phi) = \frac{3V_0R^2\sin\theta}{\pi . d_d^3 . (1-\cos\theta.\cos\phi)} \qquad 1-\cos^2\theta.\sin^2\phi \qquad (7)$$

Moments of $f(\phi)$ can be obtained using (7) along with (2), (3) and (4). Of special interest in the field of combustion is the so called Volume-Surface mean diameter or Sauter diameter, $\bar{X}_{VS}$, defined as (Marshall, 1954):

$$\bar{X}_{VS} = \frac{\Sigma X(\phi_j)^3 \; . \; f(\phi_j).\Delta\phi_j}{\Sigma X(\phi_j)^2 \; . \; f(\phi_j).\Delta\phi_j} \qquad (8)$$

RESULTS

Figure 3 shows the Sauter mean diameter for several liquids in a given configuration. Notice that, as in the case of twin impinging jets (Couto, 1992), a minimum occurs at a given value of ϕ.

CONCLUDING REMARKS

This interesting feature (a minimum value for the Sauter diameter) suggests that the optimum impacting angle for the splash plate atomizer is around 35°, as this situation allows for a maximum fuel evaporation rate.

The authors feel that this formulation will allow the increased use of these simple atomizers, although it is known that injectors consisting of PAT (Preatomized triplet) elements have been used in liquid rocket engines. Each PAT element consists of two oxidizer splash plate orifices and a single fuel, hollow cone swirler, so that fuel and oxidizer are atomized prior to contact. Recent experimental results have shown that this arrangement leads to energy release efficiencies grater then 99% at their design oxidizer/fuel ratio (Shbenman, 1991).

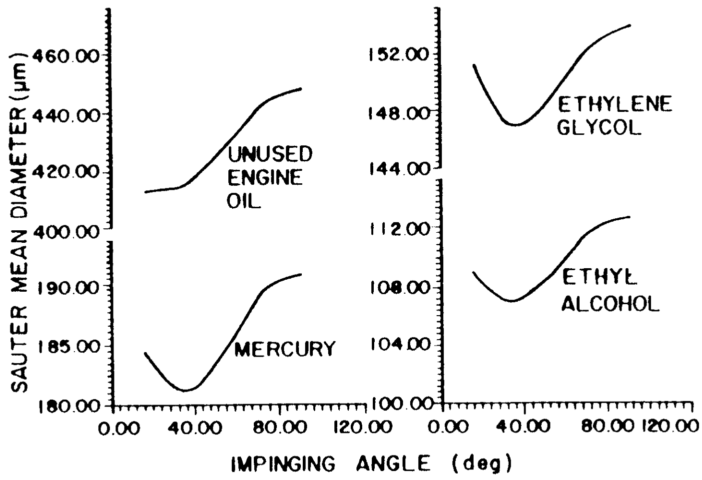

Figure 3. Sauter mean diameter for various liquids vs impinging angle θ for a given configuration (R=0,05cm, U=3000cm.sec^{-1}).

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