A New General Equation of Mean Particle Size for Different Atomization Processes

Yunzhong Liu[1,a], Yuanyuan Li[1,b]

[1]South China University of Technology, College of Mechanical Engineering, Wushan Road, Guangzhou 510640, Guangdong Province, P. R. China
[a]yzhliu@scut.edu.cn, [b]mehjli@scut.edu.cn

Abstract

Based on theoretical analysis, a new general equation of mean particle size applicable to both conventional atomization methods and new atomization processes is presented. In gas atomization, it is equivalent with and can be changed into Lubanska Equation. In centrifugal atomization, it can be changed into the equations that are currently the most widely used. In water atomization, it is similar to the equation proposed by Grandzol and Tallmadge. According to the universal equation, new correlations for mean particle size in novel atomization processes such as Hybrid Atomization and Multistage Atomization were proposed and agreed with our experimental data well.

Keywords : metal atomization, general atomization equation, mean particle size

1. Introduction

Metal atomization is a powder-making technology that involves breaking down melts from bulk liquid into fine droplets. In the past fifty years, different empirical correlations or formulae were presented for different type of atomization methods and even in the same method. Usually these empirical formulae have only limited application to a specific atomization method or certain atomization conditions. However, it was thought very difficult to establish an atomization equation for gas atomization or water atomization by physical modeling and mathematical analysis, let alone establish a universal equation. In this work, it is assumed that the basic law of liquid breakup from bulk into droplets can be applied to all kinds of atomization. By means of theoretical analysis and correlation, a general equation for melt atomization was obtained firstly and changed into a different formula for each atomization method.

2. Analyses and Results

Firstly some dimensionless parameters or groups are defined as follows.

(1) E_a is defined as a dimensionless, effective atomization work. It is equal to the ratio of the work used for melt disintegration and the work used for melt viscous deformation in atomization, and $E_a \propto (We/Re)$. Since metallic melts usually belong to viscous liquids, a viscous deformation takes place before their final breakup in atomization. This deformation actually postpones or hinders the melt disintegration. Since only a small amount of energy is used for melt breakup, E_a is the effective atomization work to some degree. Thus, the ratio (We/Re) can be regarded as a parameter for the breakup ability of atomizer.

(2) Q is defined as a dimensionless, relative flow rate of a fluid under an external force and Q=inertial flow velocity of fluid / viscous flow rate of fluid. Q_t means the total dimensionless relative flow rate between melts and atomizing media. Q_m, Q_g, and Q_w mean the dimensionless flow rates of melts, gas and water, respectively, in atomization. In fact, Q can be regarded as a reduced flow rate or volume of a fluid in this work.

(3) A factor ε is defined as the breakup degree of melts in atomization. It is equal to the ratio of the surface area for total droplets after atomization and the surface area for melts before atomization. In a twin-fluid atomization, $\varepsilon=(3/2)\cdot(D/d)$. So the ratio (D/d) can represent the breakup degree of melts in atomization. A similar equation can also be obtained in centrifugal atomization.

(4) Re_s is defined as Reynolds number based on surface flow. To some degree, it can reflect the flow type and instability of interface between melts and atomizing media. In fact, in atomization studies, the mean particle sizes of powders often depend heavily on some key parameters such as Weber number (We), Reynolds number (Re) and gas to melt mass flow ratio (GMR), etc. The following law was observed in both Lubanska's Equation for gas atomization [1] and Halada's work for centrifugal atomization [2]: $(d/D) \propto We^{-1/2}$. Also, as shown in the work on hybrid atomization, the ratio (Re/We) is in inversely proportional to the breakup ability of a centrifugal atomizer in the hybrid atomization mode diagram. According to the conventional definition, We stands for a ratio of inertial force and surface tension. It controls the breakup ability of melts by atomizer.

© Korean Powder Metallurgy Institute

Table 1. Calculation of dimensionless parameters in different atomization methods

Parameter	Gas Atomization	Centrifugal Atomization	Water Atomization
Re	VD/ν_m	VD/ν_m	VD/ν_m
		$=2\rho_m\omega^2R^2/\mu_m$	
Re_s	VD/ν_m	$V_R\delta/\nu_m$	VD/ν_m
		$=\rho_m q/(2\pi R\mu_m)$	
We	$\rho_m V^2D/\sigma_m$	$\rho_m V^2D/\sigma_m$	$\rho_m V^2D/\sigma_m$
		$=2\rho_m\omega^2R^3/\sigma_m$	
Q_g	$q_g/[\pi D(VR\nu_g)^{1/2}]$		
Q_m	$q_m/[\pi D(VR\nu_m)^{1/2}]$	$q_m/[\pi D(VR\nu_m)^{1/2}]$	$q_m/[\pi D(VR\nu_m)^{1/2}]$
Q_w			$q_w/[\pi D(VR\nu_w)^{1/2}]$
Q_t	$\approx [2(1+M/A)*VD/\nu_g]^{1/2}/4$	$q_m/(2\pi R^2\omega^{0.5}\nu_m^{0.5})$	$\approx Q_w=(2VD/\nu_w)^{1/2}/4$
Notes		$Q_t=Q_m$	$M<<W$; $Q_m<<Q_w$

Re stands for the ratio of inertial force and viscous force, which will decide the flow type and stability of melts before their disintegration in atomization. To some degree, the ratio (Re/We) can be regarded as a dimensionless number group for the breakup ability of melts by atomizer in atomization.

The relatedparameters can be calculated as in Table 1 where V is the relative velocity between melts and atomizing media; R is the inner radius of nozzle in twin-fluid atomization or disk radius in centrifugal atomization. q_m, q_g, q_w are the volume flow rates of melts, gas and water, respectively, in the corresponding atomization methods. ω is angular velocity of centrifugal atomizer. ρ_m, σ_m, ν_m, μ_m are the density, surface tension, viscosity of melts in atomization respectively. ν_g, ν_w are the viscosity of gas and water in atomization respectively.

In gas and centrifugal atomization, the main atomization mechanism is the shearing mechanism. However, in water atomization, the main atomization mechanism is the impacting mechanism. In case of the shearing mechanism, $E_a=F_\tau\cdot S=\sigma_m\cdot\Delta S$. As the total droplet surface area after atomization S_2 is much bigger than the melt surface area before atomization S_1, ε and (D/d) can be used as the increment of surface area ΔS since $\Delta S\approx S_2$ and $S_2=\varepsilon$, then $E_a \propto \sigma_m(D/d)^2$, thus $(D/d) \propto E_a^{1/2} \propto (We/Re)^{1/2}$. Meanwhile, in case of an atomization for the impacting mechanism, $E_a=2\cdot(1/2)\cdot(m/2)\cdot V^2=(F_i\cdot\Delta t)^2/(2m) \propto \sigma_m\cdot\Delta S \propto \sigma_m(D/d)^2$. So in both cases, $(D/d) \propto E_a^{1/2} \propto (We/Re)^{1/2}$. On the other hand, under the same breakup work or ability of atomizer, $\Delta S \propto 1/Q_t$, then $(D/d) \propto 1/Q_t$. If Re_s is regarded as a parameter for the flow instability of the melt/atomizing media interface, $\Delta S \propto Re_s$ and $\Delta S \propto Re_s/Q_t$, then $(D/d) \propto (Re_s/Q_t)$. Therefore $D/d \propto (Re_s/Q_t)\cdot (We/Re)^{1/2}$.

Based on the above analysis, the following atomization equation is formed.

$$d/D=k_0\cdot(Q_t/Re_s)\cdot (Re/We)^{1/2} \qquad (1)$$

where k_0 is a constant.

According to Table 1, the new equation can change into different forms in different kinds of atomization methods. In gas atomization, $Re=Re_s$, $Q_t\approx[2(1+M/A)\cdot VD/\nu_g]^{1/2}/4$. So Eq. 1 can be transformed into Lubanska's Equation [1]: $d/D=K_g[(\nu_m/\nu_g)\cdot(1+ /A)/We]^{1/2}$. In centrifugal atomization, $Q_t=Q_m=q_m/(2\pi R^2\omega^{0.5}\nu_m^{0.5})$. Thus Eq. 1 becomes the equation adopted widely and agrees well with the empirical correlation by Halada et al [2]: $d/D=K_cWe^{-1/2}$. In water atomization, $M<<W$, $Q_m<<Q_w$, $Q_t\approx Q_w=(2VD/\nu_w)^{1/2}/4$. Therefore, Eq. 1 changes into the form which agrees well with the empirical formula by Grandzol et al. [3]: $d=K_w\cdot[(\nu_m/\nu_w)\cdot (\sigma_m/\rho_m)\cdot D]^{1/2}\cdot(1/V)\approx A/V_w$. In the hybrid atomization process, Eq. 1 can be transformed into the equation which has been verified by experimental data and empirical correlation by Liu et al [4]: $d/D=K_h\cdot\eta\cdot We^{-1/2}$. In Multistage Atomization process, a new equation is obtained: $d/D=\eta_g\cdot\eta_w\cdot\eta_c$ and verified by our previous work [5].

3. Summary

Based on theoretical analyses, a universal atomization equation was proposed for the mean particle sizes of powders in melt atomization. The new equation can be changed into some empirical correlations in conventional atomization methods and novel atomization processes.

4. References

1. H. Lubanska, Journal of Metals, **22[1],** 45(1970).
2. K. Halada and H. Suga, Powder and Powder Metallurgy (in Japanese), **37[4],** 492(1990).
3. R. J. Grandzol and J. A. Tallmadge, AM. Inst. Chem. Engineers J., **19[10],** 1149(1973).
4. Y. Liu, K. Minagawa, H. Kakisawa and K. Halada, Int. J. Powder Metallurgy, **39[2],** 29(2003).
5. Y. Liu and Z. Chen, SDMA 2003 & ICSF V, p. 67(2003)

© Korean Powder Metallurgy Institute