Development of Operating Pressure Diagram for Free Fall Gas Atomization of Liquid Metals

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1. Introduction

Gas atomization of liquid metals is widely used to produce metal powder and preforms of a variety of geometries.1,2) Of the various gas atomization techniques, confined (also known as closed type) and free fall (also known as open type) techniques are widely used in the powder metallurgy industry. Figure 1 shows a schematic arrangement of some components of the gas atomization unit.3) In the confined gas atomization (Fig. 1(a)), molten metal travels a very short distance before being impinged by the high-energy atomization gas jets. This type of atomizer is very sensitive to metal freeze-up, a condition that occurs when the liquid metal at the end of the liquid delivery tube solidifies prematurely. In the free fall atomization technique liquid metal is allowed to fall freely before it is disintegrated in the gas field around the geometric point of an atomizer. Since the liquid delivery tube is not in contact with the atomization gas, nozzle freeze-up is avoided.

In the present study an attempt has been made to evolve a suitable criterion for the design of gas atomizers used in the free fall gas atomization using the knowledge of the dynamics of gas flow rate and interaction between the atomizing field and the molten stream.

2. Evolution of a Criterion

In the free fall atomization, the atomizing field of certain amount of gas and velocity forms due to impingement of gas jets, and is located several distance away from the atomizer as compared to close type, where the said field is just near to the atomizer. As a consequence higher pressures are required to produce atomizing field of same velocity in free fall atomization. But higher velocity of gas will also cause the droplets to fly away at higher velocities from the atomizing zone in upward, i.e. toward the atomizer and downward direction, i.e. toward the powder collection tray, and also consume higher amount of gas. The droplets may hit the atomizer and begin to deposit around the nozzle and the liquid metal delivery tube. The deposit may produce hindrances to flow of gas and molten metal and affect adversely the process of atomization.

In the open technical literature there is hardly quantitative information available between the metal build-up phenomenon and the atomizer related parameters. See and Johnston had studied the atomization of freely falling molten stream of lead and tin by using atomizers of different apex angle.4) They observed metal build-up on the ring of an atomizer whose apex angle was 90 deg. Uslan et al. studied size and characteristics of gas atomized powders using free fall type atomizer.5) They observed filling of liquid metal in the nozzle central hole, which on solidification blocked the nozzle. According to them free fall nozzle is normally safe to use up to certain limiting pressures. No quantification of the results is reported. Singh et al. had studied metal build-up phenomenon during free fall atomization of lead, aluminum and zinc.6) The details of the atomizers are given elsewhere.6) They observed metal build-up around the nozzle and the liquid delivery tube whenever atomization of either lead or aluminum or zinc was carried out at or above the particular velocity of atomizing gas. This particular value of velocity was called limiting velocity and was found to be a function of density of metal, free fall distance of the stream and apex angle of the atomizer. They could develop the following correlation to determine the limiting velocity:

$$V_L = 2.7 \times 10^{3} \rho^{0.22} \frac{L}{a} \exp (-0.9)$$

For a given type of metal, the Eq. (1) suggests that it is safe to atomize a freely falling metal stream at the velocity $V_L$. However, atomization can still be carried-out at velocities greater than $V_L$, which though produce fine powder but may lead to metal build-up. Thus, pressure should be selected such that a given mass flow rate of the gas is accelerated maximum up to $V_L$.

3. Selection of Pressure and Mass Flow Rate of Gas

Singh et al. had studied the velocity of gas in the atomizing gas field produced by atomizers of different focal lengths, apex angles, and nozzle number and diameters at various pressures.7) They measured large variations in the velocity of gas within the said field. Further maximum velocity of gas was observed at the geometric point of each atomizer. At all other locations the velocity was a fraction of the maximum velocity of the gas. For the convenience they used maximum velocity to correlate the data and reported the following correlation:

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Note

Figure 1. Design of atomizers.

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For the condition that the metal build-up must not occur during atomization $V_g$ must either be equal to or less than $V_L$. Considering equality sign and assuming $F=L$, we get, with the help of Eqs. (1) and (2) the following relationship to determine the limiting plenum pressure, $P_L$ to supply a given amount of gas:

$$P_L = 9.24 \times 10^9 (p^{0.23} F^{-1.43} a^{-0.97} d^{-0.5})$$

In the Eq. (3), $\rho$ is in kg/m$^3$, $F$ in m, ($\alpha$ in degree and $d$ in m in order to get $P_L$ in Pascal. For a given atomizer, Eq. (3) determines the limiting plenum pressure at or below which no build-up of metal would occur on the atomizer. According to Eq. (3) $P_L$ increases with the increase in either $\rho$ or $F$ but decreases with the increase in either apex angle or nozzle diameter. Mass flow rate of gas can be determined by

$$m = 0.04042 C_d N A \alpha \sqrt{P(T_0)}$$

For a given atomizer, Eq. (4) interconnects total mass flow rate of gas with plenum pressure. The value of $C_d$ is unity for the isentropic flow and less than one for all non-isentropic flow situations.

4. Pressure–Flow Rate Diagram

Equations (3) and (4) are used to construct a diagram to determine the operating pressure and the corresponding flow rate of air for atomization of metals. Figure 2 shows the variation of limiting plenum pressure with the focal length of the atomizer of lead in the left hand side, while the corresponding flow rates of gas are plotted on the right hand side of the figure. In the above figure, the solid and dashed line is for an atomizer having apex angle of 40 deg. but nozzle dia. of 2 mm, and 3 mm respectively, whereas dotted dashed and dotted lines are for for atomizers having 60 deg. apex angle but nozzle dia. of 2 mm, and 3 mm respectively. Figure 3 shows the variation of limiting plenum pressure with the focal length for the atomization of lead, zinc and aluminum in an atomizer having 40 deg. apex angle and nozzle diameter of 2 mm. The same figure also shows the corresponding mass flow rate of the gas.

For any preselected value of $F$, $D$ and apex angle of the atomizer the maximum pressure and corresponding to this pressure the mass flow rate can be determined. For example, consider an atomizer to atomize the lead stream. The focal length of the atomizer is 100 mm and its apex angle is 40°. The atomizer consists of 4 nozzles and each nozzle has 2 mm diameter. From Fig. 2 the limiting plenum pressure (without any risk of metal deposition) is 19 bar and the total

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Fig. 2. Operating limiting plenum pressure diagram and mass flow rate of gas for atomization of lead.

Fig. 3. Operating limiting plenum pressure diagram and mass flow rate of gas for atomization of different metals.
mass flow rate of air is 0.032 kg/s passing through the said atomizer. For the same focal length the limiting pressure is 16 bar for atomization of zinc and 13.5 for aluminum as shown in Fig. 3. Atomization can still be carried-out at pressures below or above the limiting pressure. But the atomized powder would be coarser at pressures below the limiting, and finer above it but with the risk of metal deposition. It is up to the user to decide the atomization condition. The way to determine is shown in the Figs. 2 and 3.

5. Conclusions

In this study pressure to supply a given amount of gas is determined for atomization of a freely falling molten stream. It is safe to atomize the molten stream without running into the risk of metal build-up on the surface of the atomizer. By considering the limiting velocity of gas, limiting plenum pressure is determined for atomization of different metals. Higher metal densities and higher focal lengths of atomizer are associated with higher limiting plenum pressures. A diagram is given with which the limiting plenum pressure and mass flow rate of gas can be determined as a function of focal length of atomizer for different types of metals.

Nomenclature

- \( C_d \): Drag coefficient
- \( d_n \): Nozzle diameter (m)
- \( F \): Focal length (m)
- \( L \): Free fall distance (m)
- \( m \): Mass flow rate of gas (kg/s)
- \( N \): Number of nozzles
- \( P \): Plenum pressure (Pa)
- \( P_L \): Limiting plenum pressure (Pa)
- \( T_0 \): Temperature, (K)
- \( V_g \): Velocity of gas (m/s)
- \( V_L \): Limiting velocity of gas (m/s)
- \( \alpha \): Apex angle (degree)
- \( \rho \): Density of metal (kg/m³)

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