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A Theory of Hot Gas Atomisation

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Abstract

The use of hot gas in melt atomization has been widely reported, but little detailed experimental data on its precise effects and no satisfactory theory to explain them have been published. In this paper the authors present experimental data on the atomization of metals with gas at temperatures from ambient to 1000C, a semi-empirical equation relating particle size to gas temperature and flow rate, and an analysis of the gas dynamics of the atomization process that allows some insight into the process.

Keywords : Gas atomization

1. Introduction

There are increasing demands for inert gas atomized powders, particularly with fine particle sizes, for example median sizes from 30 down to 10µm. It is well known that to make fine powders is difficult, and demands the use of large amounts of gas, incurring high costs. The use of hot gas can have major economic benefits [1] as well as allowing the production of finer powders than are possible using cold gas.

2. Basic theory

There are no wholly satisfactory theories of gas atomization working from first principles. The physics of the break-up process is very complex even with cold liquids, and with metal melts at high temperatures, is currently totally intractable. One simple approach is to consider an energy balance, in which the kinetic energy in the gas jet is converted to surface energy of the powder. However it can readily be shown that the efficiency of this conversion is between 0.1% and 0.005%, so a direct relationship is not obvious. Also the energy of a gas stream from a nozzle is proportional to its mass flow, so one might expect, if efficiency was constant, a relation of the form: $D = k_1/(G_m/M)$ (1) where D is the particle size, k_1 a constant, and G_m/M the gas/metal mass flow ratio. It is found experimentally [2] that the data (for cold gas atomization) conform to an equation of the form;

$$D = k_2\,(G_v/M)^{-0.5} \qquad (2)$$

Here we define symbols as: T – Temperature K; D – Powder mass median particle size; G_m – Gas mass flow rate; G_v – Gas normal volume flow rate (at 273K, 1bar); G_a – Gas actual volume flow rate (at actual P, T); M – mass flow rate of metal melt.

One approach to the effect of temperature is to assume that the real work is done by the actual volume of gas when temperatures vary. So we re-write equation (2) as

$$D = k_3(Ga\ /M)-0.5 \qquad (3)$$

Then we simply calculate the actual cu.m of gas leaving the nozzle, taking account of its expansion with the temperature and the change of sonic velocity ($\infty T^{0.5}$). A simple theory based on this approach is presented in [3]. However the calculations are based on simple isothermal gas laws, and the real situation is entirely adiabatic, demanding a more complex analysis. DF has calculated the effects of heating a gas on the properties of the resulting jet. It is found that that, despite the mass flow rate falling with temperature ($\infty T^{-0.5}$) the total power (or kinetic energy per second) rises with ($\infty T^{0.5}$), as does the actual m^3/min. At 1000°C nitrogen can reach a velocity of 1129m/s, comparable to helium at 20C (1355m/s).

We can now take equation (3) $D = k_3(G_a/M)^{-0.5}$ But above we find G_a is $\infty T^{0.5}$ and G_m is $\infty T^{-0.5}$ So we find that $G_a = k_4\,G_m T$. We can now re-write equation (3) in terms of T and G_m/M ratio as $D = k_3(k_4 G_m T/M)^{-0.5}$, so

$$D = k_5 T^{-0.5}(G_m\ /M)^{-0.5} \qquad (4)$$

3. Experimental Data

ATZ-Evus has constructed an advanced research inert gas atomizer, equipped with a special heater capable of over 1000C. Data on the atomization of copper has been analysed, but problems in measuring the particle sizes and agglomeration have led to some scatter.

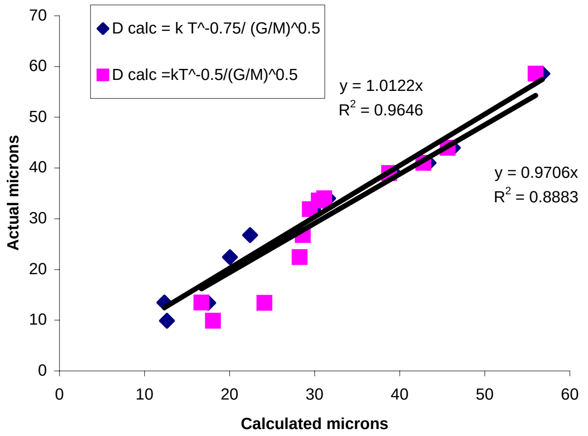

Fig. 1. Experimental data

The graph shows a plot of the actual measured median sizes plotted against the theoretical values from equation (3) with k selected to give close to y=x. The trend line is forced through zero, and a poor R^2 value of 0.888 results. All the hot gas experiments give finer results than predicted by equation (2). An equation with T-0.75 shows far better results, giving an R^2 factor of 0.964. Thus we have a theory disagreeing with experiment. The data below is for a range of pressures from 1.5-6.6MPa and the effects of pressure in this range on the kinetic energy of the jet will be quite significant.

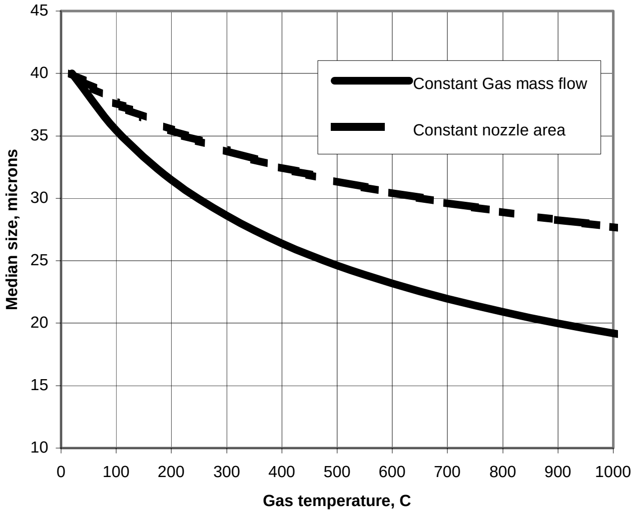

Fig. 2. Effect of gas heating on particle size

4. Practical Implications

As discussed in [1], hot gas atomization has major economic benefits and allows the production of much finer powders. The scope for making finer powder is illustrated in figure 1 above and also shown in figure 2 below, which shows the effect of simply running the same nozzle and melt flow rate, and then the effect of maintaining the G/M mass ratio by either increasing the nozzle area, or reducing the melt flow rate. Normally the minimum melt flow rate is set by freezing problems, but hot gas greatly reduces these problems, allowing even finer powders to be made.

The initial 40 micron size is just a typical value; the same curves should apply for any cold atomized particle size.

5. Summary

The proposed theory shows the following important relationships:-

$$D = k_5\, T^{-0.5}(G_m/M)^{-0.5} \qquad (4)$$

Which implies that, at constant nozzle area, and melt flow,

$$D \infty T^{-0.25} \qquad (5)$$

And at constant Gas/Metal mass flow ratio,

$$D \infty T^{-0.5} \qquad (6)$$

And at constant particle size, and melt flow, the gas flow needed,

$$G \infty T^{-1} \qquad (7)$$

The experimental data presented shows an even higher dependence on T, with index –0.75 in equation (2), but more data is needed to resolve this question. Whatever the precise relationship, it is very clear that hot gas atomization has great attractions in reducing costs and/or making finer powders.

6. References

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