Atomise polymers to maximise profits

The difficulties of mass producing micron-sized high quality powders from molten polymers can be avoided by using high pressure gas atomisation methods, suggest Joshua Otaigbe and Jon McAvoy

THE PRODUCTION OF micron-sized polymer powders from molten polymers is an attractive, facile, low energy, and economic process. Polymer powders with tailored characteristics such as particle shape and size distribution, and purity can be directly prepared from the molten state of polymers such as polyethylene-based waxes that can not be ground using conventional grinding methods. The gas atomisation process (GAP) for mass-producing high quality spherical polymer powders involves the use of high pressure (approximately $7.6MNm^{-2}$ maximum) nitrogen gas and a specifically designed nozzle to atomise a molten stream of polymer into fine droplets which cool to form spherical powders, fig 1. Powders with properties tailored to varying applications can be efficiently produced in short cycle times by changing few process control variables in a contamination-free environment, thus making the GAP a useful alternative to conventional grinding processes. These benefits of the process together with its flexibility, high throughput and facile nature can be expected to make it highly attractive to industrial processes that must be capable of mass production, safe and environmentally-benign operation.

The targeted applications of the powders include uses as powder spray coatings, as formulating ingredients for functional coatings, and as raw materials for solid-state compacting of polymer alloys and composites. In these applications, the required properties of the powders include purity and uniform micron-sized spherical particles. These properties are essential for free-flowing powders with optimal surface area, which in turn leads to improved handling and performance during service of the prepared product.

Commercial organic polymer powders are produced by conventional grinding of extruded polymer pellets, often under cryogenic tempera-

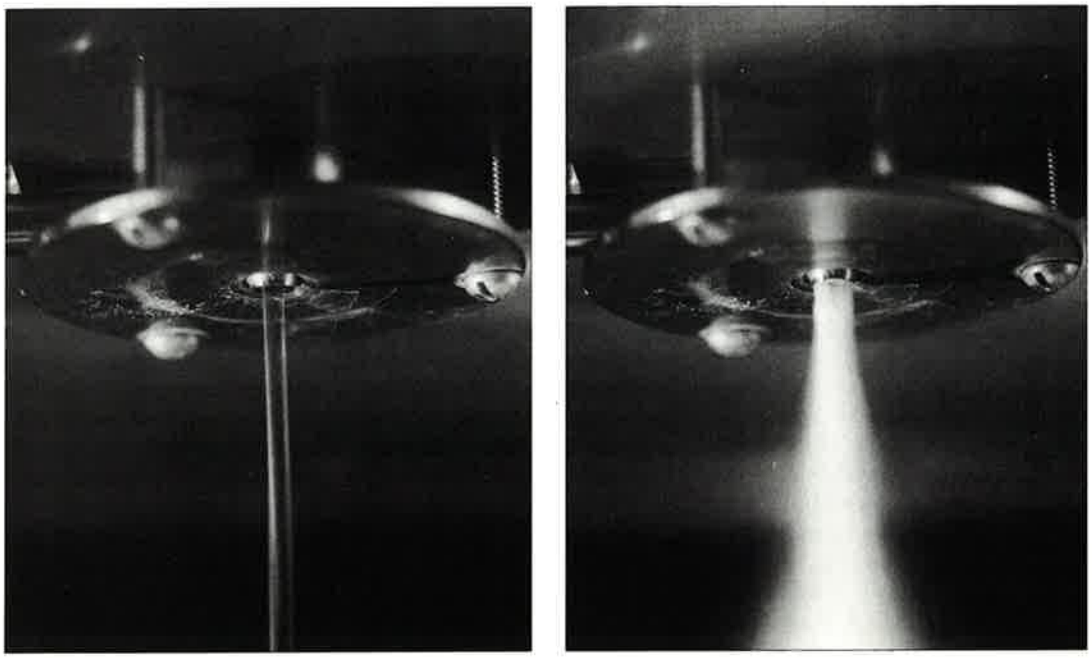


Figure 1
The molten polymer stream before (left) and (after) gas atomisation

Professor JU Otaigbe is in the Department of Materials Science and Engineering at Iowa State University, USA. Mr J McAvoy was formerly a research student in the same department, but is now employed at John Deere Harvester, USA

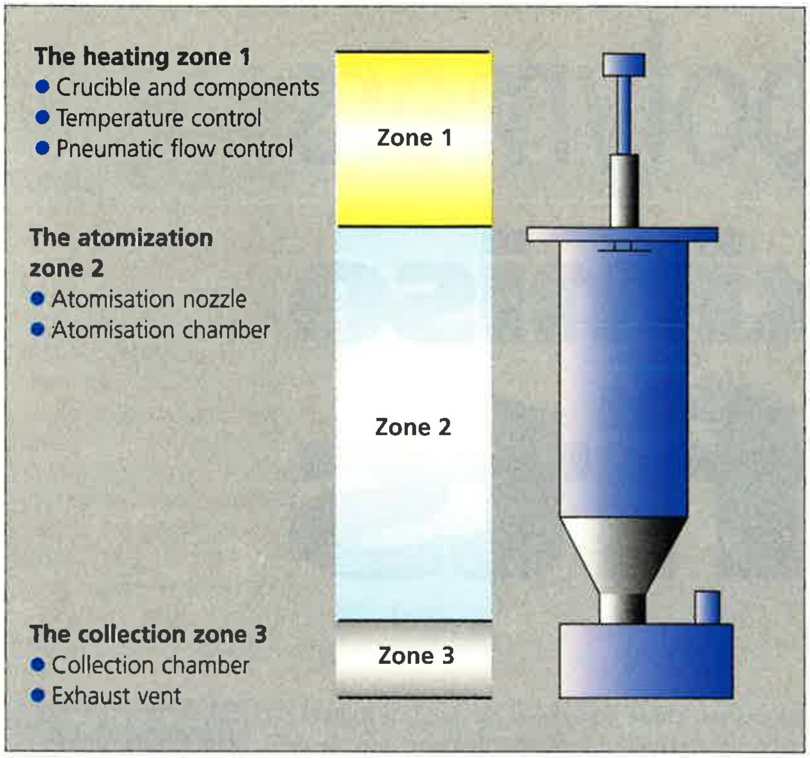


Figure 2
Schematic of GAP showing the key zones and components

ture conditions. Grinding is undesirable because it is expensive, highly energy intensive, and sensitive to contamination from the grinding equipment and from environmental pollution. Because of the erratic nature of the grinding process it is almost impossible to control the quality and distribution of the powders and the size and shape of the particles.

The GAP method is an alternative route to mass producing polymer powders and eliminates most of the problems of conventional grinding operations. In addition, the simplicity and versatility of GAP mean that the equipment can be constructed from readily available construction materials such as steel (used in the crucible) and impact-resistant crystal-clear polycarbonate (used in the atomisation chamber), fig 2. The optical clarity of the latter material allows direct real-time visualisation of the atomisation of the molten polymer as it exits the crucible. This process involves heating the material in a crucible until the desired atomisation temperature is reached. Once the material reaches this temperature it is forced out of the crucible through a circular channel (the pour tube) into the atomisation nozzle where it is atomised into fine particles by the high pressure nitrogen gas. The particles cool as they fall through the atomisation chamber to form micron-sized powders, which collect in a vented chamber, fig 2. Additional details of the GAP process have been reported.

The GAP feasibility studies and process development efforts have focused on using commercial polyethylenes (eg Hoechst Celanese PE130 and PE520) as the model material because polyethylenes are presently the largest volume commodity plastics used in the US with over 9 x 10^9kg produced annually. The high consumption, low toxicity, low molecular weights (2000–10000g/mol), and low melting temperatures (approximately 200°C) of PE130 and PE520 make them ideal materials for atomisation. Thus far, only the low molecular weight polyethylenes have been atomised into fine powders with changeable particle shapes and size distributions (0–250μm). The studies conducted thus far show that the quality and properties of the product powders depend on three key processing variables: polymer melt temperature, gas atomisation pressure, and melt stream size (or pour tube diameter), fig 3 and table 1. The particles in gas-atomised powders are spherical with smooth surfaces and near uniform sizes whereas those produced by conventional grinding are not. Other particle shapes such as whiskers and elongated spheres can be produced under specific processing conditions such as using low atomisation pressures (approximately $2MNm^{-2}$). Typically, the whiskers have diameters of about 100nm and lengths of a few millimeters.

Computer simulations of GAP to expand the method to produce powders from other polymers with tailored powdered characteristics for wide applications are continuing. As already mentioned, potential applications of the product powders include use as formulation ingredients for functional coatings tailored to specific biochemical engineering application areas, such as personal hygiene and beauty care products, packaging, and other disposable and/or recyclable plastic products. Other applications include polymer dispersions or emulsions in environmentally-friendly solvents, feedstocks for solid-state compacting of polymer alloys, and powder spray coatings. As an example, PE520 is designed for use in paints to increase matting effects and to mar resistance of the painted surface. Other advantages to using polymer powder additives in paints are improved sandability, improved smoothness, improved rheological properties, prevention of pigment settling and metal marking, and water repellence. Because of the flexibility, versatility, and economy offered by GAP, it can be expected to be attractive to polymer manufacturers, processors, and end users.

Because the polymers can be atomised in a relatively narrow temperature range (190–220°C), control of temperature in GAP must be precise so as to avoid potential thermal degradation of the molten polymer prior to atomisation. This requirement can be met by heating the polymer in the crucible under a blanket of nitrogen gas using precisely controlled band heaters with thermocouples strategically placed in the melt. Obviously, polymers that show different rheological properties under conditions which they are likely to encounter during atomisation can be expected to atomise differently. For example, it is found that at low pressures (approximately $2MNm^{-2}$) the shear induced by the gas jets on the molten polymer at the instant of melt disintegration is not enough to completely overcome the internal elastic stresses present in the molten polymer. This leads to the formation of whiskers and elongated spheres rather than absolute spheres, fig 3. For the polyethylenes studied thus far, it has been found that the formation of whiskers and elongated spheres can be avoided by using high gas atomisation pressures (approximately 7.6MNm^{-2}), fig 3. It appears that a mixture of whiskers and spheres would be ideal for making self-reinforced polymer powders that can be used for applications requiring improved mechanical properties. Investigations on expanding the employment of GAP to other polymers with vastly different thermal and rheological properties are continuing.

More recently, 50/50 blends of PE130 and ultra-low melting polyphosphate glass composition have been successfully atomised under conditions that were used to atomise the pure PE130 polymer. This result confirms the expectation of the broad application of GAP to many fields, such as in producing polymer alloys, glass–polymer alloys, *in situ* composites, and related products with tailored properties for beneficial uses in many areas such as decorative or protective coatings, polymer-supported heterogeneous catalysts, and in producing lightweight structural composites. The structural composites can be easily fabricated by applying established solid-state powder compaction methods to the gas-atomised composite powders to form compacts with varying shapes and sizes.

The research conducted thus far has provided valuable insight into GAP diagnostic control systems, dynamics and mechanisms of powder formation. This knowledge can be used to expand the application of the method to include the production of other kinds of materials with desirable properties for beneficial uses. The desirable properties of the powders include the following: purity; particle shape; particle size; and size distribution. The many teething problems of GAP when it is applied to polymers and composites are now understood and can be controlled and managed in order to produce powders with tailored characteristics. The technology of GAP has now advanced to a stage of finding more applications in the areas of polymer engineering, composite engineering, and of scaling-up to mass production of the fine polymer powders.

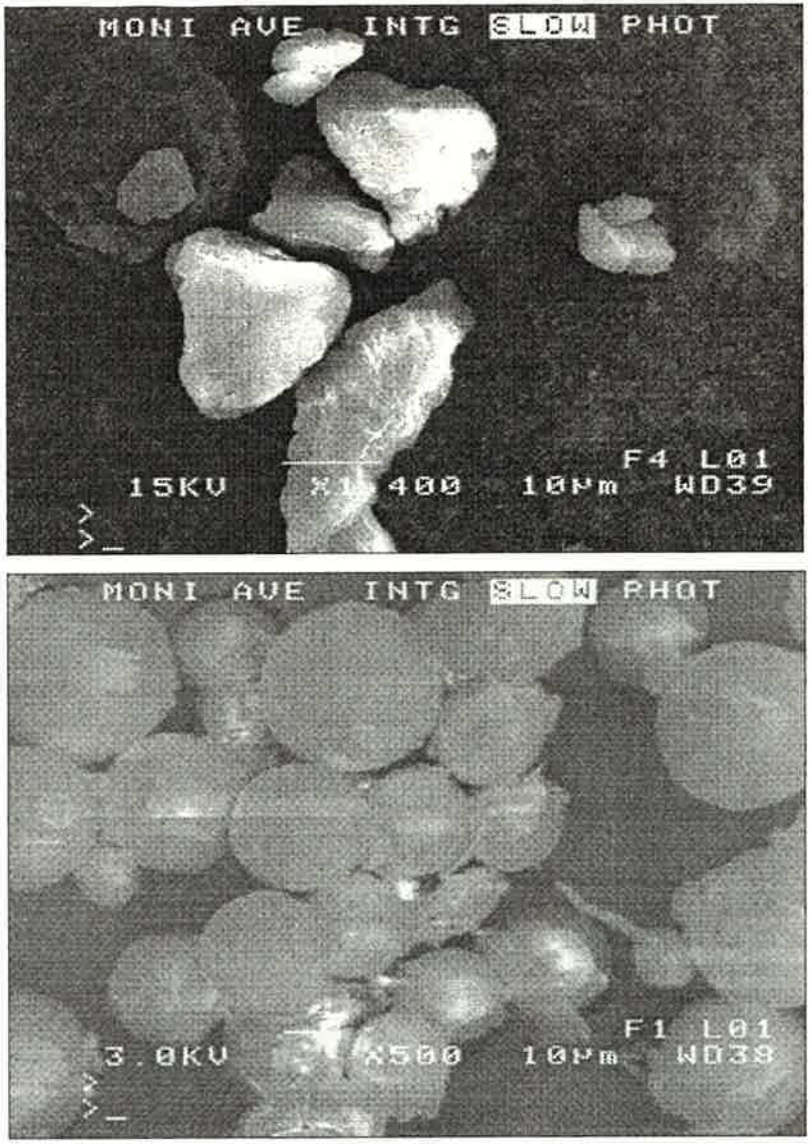
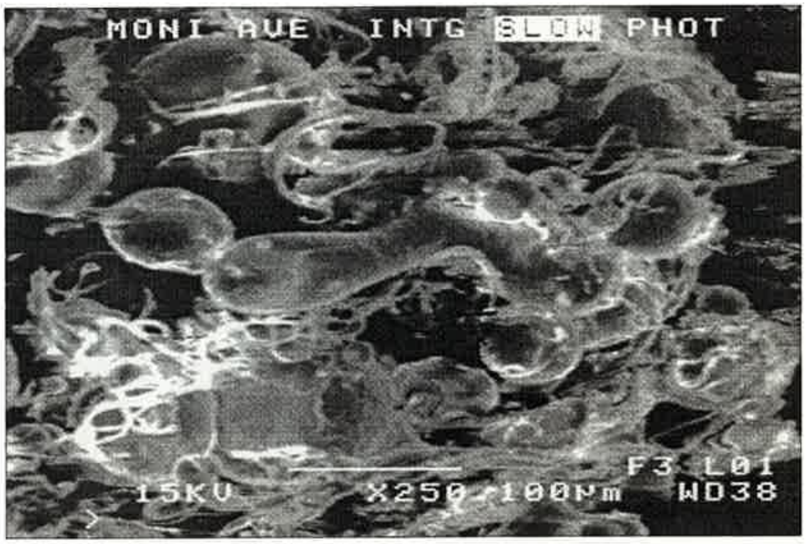


Figure 3 *SEM of commercially ground PE-based wax (top), PE520 atomised at pressures of 7.6MNm^{-2} (above) and 2MNm^{-2} (below). (The PE520 was atomised at a temperature of 190°C in both cases)*



Acknowledgements

The authors thank Iver Anderson, Ames Laboratory, Hoechst-Celanese and Allied Signal Inc without whose support and encouragement this work would not have been possible. The computer simulation contribution of Don Noid, RE Tuzun, and Bobby Sumpter (Oak Ridge National Laboratory) to this work is thankfully acknowledged. Financial support of this work by the Center for Advanced Technology Development and Iowa State University is gratefully acknowledged.

Further reading

- JM McAvoy, JU Otaigbe, Gas Atomisation of polymers, *SPE ANTEC Tech Papers*, 1997, **43**, 2071.
- RE Tuzun, DW Noid, BG Sumpter, JU Otaigbe, *Proc ACS: Div Polym Mat Sci*, 1997, **76**, 585.
- JU Otaigbe, JM McAvoy, IE Anderson, US patent application 09-0530, filed 17 July, 1996.
- JP Jog, *Adv Polym Tech*, 1993, **12**, 281–293.