Shape Makes a Difference

Using metallic flakes instead of powder as a feedstock might significantly improve process productivity.

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A recent study[1] and early production experience have shown that the shape of the metallic particles used as feedstock in chemical processes may improve the productivity of the process by as much as 40%. This improved productivity is a combination of increased throughput of the product, reduced material costs and elimination of secondary steps and additives required in the existing process.

In the study, a simple experiment was devised to evaluate the effect of particle shape using aluminum particles. The experiment consisted of dissolving a specified mass of a wide variety of particle shapes in an aqueous sodium hydroxide solution and observing the reaction rate behavior and time for the reaction to go to completion. The results of this experiment indicated that properly sized flakes (planes) produce a more uniform and optimum reaction than powders (spheres) or chopped wire or needles (cylinders).

For more than 100 years, the chemical industry has prepared commercial products containing one or more metals by dissolving the metals from base metal stock. Metal powders, shot and chopped wire have been used as feedstock for more than 50 years. These metals were specified for use in the chemical process by particle size and purity. The shape of the particles was determined by the process to produce the particles.

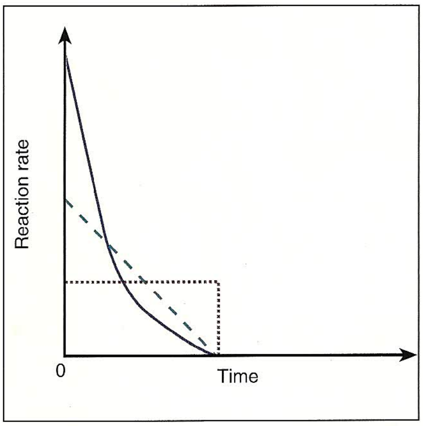
Metallic Particle Chemistry

Most chemical reactions involving the dissolution of metals are exothermic in nature. The release of energy and gas requires that the processing equipment for such reactions be designed to handle and control the maximum levels of temperature and pressure for a specified throughput. Thus, the ideal situation is a reaction or dissolution rate that is constant from the time the feedstock is introduced until it is completely dissolved. This reaction would fully utilize the capital equipment and minimize the process time per unit of chemical throughput.

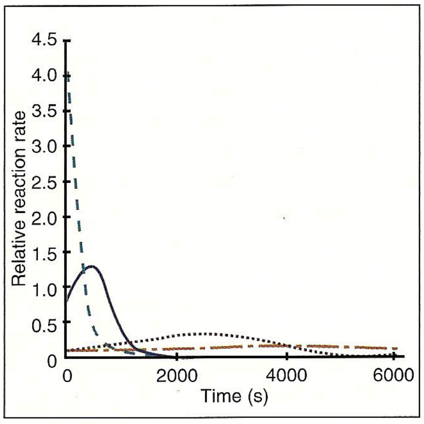
It has been shown that the reaction rate of a dissolution process is proportional to the total surface area of the feedstock material used in the process. For a given mass of feedstock, the initial dissolution rate is proportional to the initial surface:volume ratio of the particulates. However, as the particles dissolve and get smaller, the reaction rate changes depending on the change in the total area of the particles. Thus, the rate of dissolution is strongly influenced by the geometry of the particles and the size distribution of the particles.

With the advent of the rapid solidification process, a new dimension has been added to the chemical industry. Metal particles with fine grain structures and tailored shapes and sizes can be produced economically for the first time. Now, metal particles can be shaped to optimize the reaction rate and the output of chemical processes.

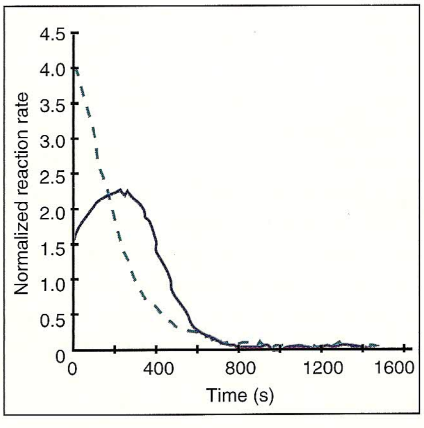
In the current study, three common shapes of feedstock material were examined: spheres (powders), cylinders (chopped wire or needles) and planes (flakes). Ideally, the



Dissolution reaction rate of identical mass particles vs time for ideal feedstock particle geometries ((—) sphere, (---) cylinder and (···) plane (not to scale)).



Normalized reaction rate for particles of dissimilar masses ((—) plane (30 μm thick flakes, K-102), (---) powder (spheres, 60% < 105 μm diameter), (···) cylinder (500 μm diameter needles, VC-350) and (– · –) tadpole (1270 μm diameter)).



Relative reaction rates of (—) flakes (K-109, ~0.5 mm² × 25 μm thick) and (---) spheres (powder A, 60% <105 μm diameter).

surface area of a sphere ($4\pi r^2$) decreases as the square of the radius, the surface area of a cylinder ($2\pi rL$) decreases directly with the radius and the surface area of a plane ($2A$) with a thickness t remains constant until the material is dissolved.

The Experiment

To confirm this proposition, a simple experiment was devised. The rate of pressure increase in a closed vessel correlates to the chemical reaction rate behavior with time. Therefore, a simple experiment was chosen to generate gas in a closed container. In this case, aluminum was dissolved in an aqueous sodium hydroxide solution. The chemical reaction is:

$$2Al(s) + 2NaOH(aq) + 6H_2O(liq) \rightarrow 2Na^+(aq) + 2Al(OH)_4^-(aq) + 3H_2(g)$$

This reaction produces hydrogen gas with moderate heat generation and corresponding temperature increase. The reaction goes to completion, producing 1.25 L of hydrogen (STP) for each gram of aluminum. In the laboratory, 1.25 g of aluminum was dissolved in 500 mL of aqueous sodium hydroxide.

The chemical reaction was measured as a pressure buildup. Because the reaction goes to completion, it is possible to normalize the pressure data to a per unit mass of aluminum reacted. Therefore, the pressure buildup is simply the fraction of aluminum reacted.

For the experimental program, 11 different aluminum particles and powders were evaluated. They ranged from large flakes weighing almost 6 mg per particle to fine spherical powders weighing 0.05 μg per particle.

Shape Makes a Difference

The results of the experimental program show that particle shape dramatically changes the process reaction rate. The reaction rates of flakes (K-102, ~1 mm² and 30 μm thick), a powder (size distribution with 60% <105 μm diameter) and larger needles (cylinders) and tadpoles (cylinder-like) were plotted and compared with the ideal curves.

First, the shapes of the experimental curves approximate the shapes of the ideal curves. Second, although the reaction time is approximately the same for the powder and flakes, the reaction rate of the powder changes by a factor of four, whereas the reaction rate of the flakes changes by a factor of <1.3.

The lower reaction rate and, therefore, longer reaction time of the needles and tadpoles is attributed to their larger size as well as the shape of the particles. Individual needles and tadpoles weighed 10 times as much as the flakes.

For equal masses of flakes and powder, the time for total dissolution is approximately the same. However, the reaction rate of the flake has a much lower maximum and is more constant than the powder. This relatively constant reaction rate is one of the factors that translates into improved process productivity when flakes are substituted for existing feedstock.

Most chemical process systems are designed with appropriate safety factors to accommodate pressure and temperature corresponding to the optimum reaction rate. The economics of the process are optimized when this rate is achieved on a continuous basis. Approximately three times more reactants could be processed in the same time at the same reaction rate if 30 μm thick flakes are the particulate feedstock rather than a powder that contains 60% spheres <105 mm in diameter. ■

Reference

[1]D. J. Statman and J. N. Anno, "A Study of the Effect of Particle Size and Shape on the Dissolution Rate of Aluminum," Research Dynamics Inc., Cincinnati, Ohio, 1995.