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Challenges in the scale-up of particulate processes—an industrial perspective

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Abstract

Studies by the Rand Corporation in the 1980s identified substantial differences in the scale-up and start-up performance of plants processing particles versus those processing liquids or gases. These differences were inevitably unfavorable. Particulate process plants take longer to start up and are less likely to achieve desired production rates. Facility operators often underestimate the challenges involved. These problems generally relate to an inadequate understanding of the behavior of particle systems. Many of these behaviors are sensitive to process scale or process history in ways that would not be expected by engineers familiar only with liquid or gas systems. Empiricism must often substitute for first principles. Modeling provides some answers, but often not enough to eliminate the need to operate pilot plants. This paper reviews some of the unit operations involved in particle processing and highlights scale-up issues involved. The use of information from suppliers and other third parties is discussed, as well as scale-up strategies in competitive or regulated industries.

Keywords: Scale up; Start up; Process plant; Merrow; Rand; Pilot plant; Particle processing

1. Introduction

The scale-up of particulate processes has been a challenge since the advent of the industrial age. Processes that were once performed by hand and guided by experience were enlarged by simply increasing the size of the equipment. Problems naturally occurred. However, unlike many similar situations in chemical or mechanical engineering, the problems in particle processing were often *not* resolved through the development of a fundamental understanding of the underlying physical phenomena. Useful equations such as the ideal gas law ($PV=nRT$) in chemistry have few counterparts in particle technology. In many cases, solutions to scale-up problems were developed by trial and error, a practical approach but one that has the unfortunate consequence of dooming each generation to repeat the experiments of its ancestors. While our empirical and computational methods have become more sophisticated, there is still a remarkable lack of "first principle" methods to design particle processes. Merrow [1] aptly describes this as the "theoretical poverty of solids processing". Progress has been limited by the widespread perception in industry that there are no fundamental principles for some aspects of particle technology, leading them to conclude that research is pointless and trial and error approaches are required [2]. There is a curious resignation to the status quo on the part of many plant operators. The general ignorance of particle technology in industry will cause some to simply hope that problems will go away instead of searching for reasons for unusual phenomena.

Particle technologists often work within their own specialties, such as the unit operations of particle formation, solid/liquid separation, and solids handling. Each may try to optimize his operation. However, a synergistic view of the entire process is required in order to achieve business success. For example, no business enterprise would want a highly efficient crystallization process that generates fine, fragile crystals that cannot be de-watered and will break up into fines in downstream handling. Fig. 1 illustrates the progressive degradation of particles that can occur as they pass through the unit operations of a crystallization plant.

Globalization and stagnation in some industrial sectors has placed mutually exclusive goals upon business management. There is a new emphasis on efficiency, and simulta-

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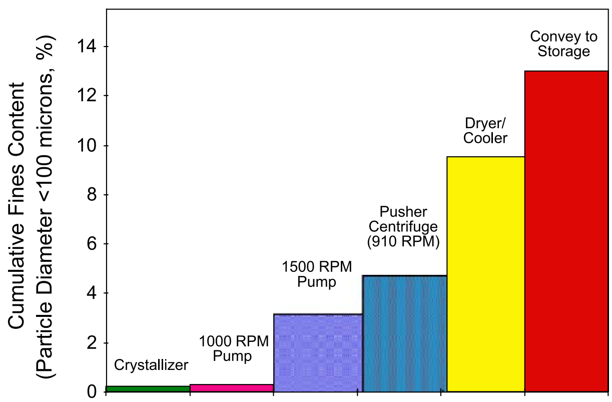

Fig. 1. Progressive attrition of crystals during processing and handling. Data provided by Ross Kendall of DuPont from original documents by E. Kratz and F. Hoyer of Escher Wyss AG, Zurich, Switzerland.

neously great pressure to reduce cost by cutting operating staff and plant project teams. These groups are often the repositories of unwritten empirical knowledge about particle processes. Existing plants are often running at full capacity, leaving no time for basic experiments that may provide data for new plants. At the same time, many industries are focussed on the growth that can only come from new products, shifting research resources away from fundamental understanding and optimization of existing processes.

2. The Rand and Merrow reports

In the early 1980's, The Rand Corporation, a private research organization, studied R&D needs in solids processing. The work was sponsored by the United States Department of Energy and a consortium of oil and chemical companies. It followed a period of significant difficulties in the start-up of new synthetic fuels plants. The Rand Corporation reviewed the performance of 37 new plants, using data provided by 25 companies.

One of the Rand study authors, E.W. Merrow, described the work in a landmark 1985 publication [1]. This publication, detailing the poor performance of solids processing plants, is familiar to anyone who either writes or reviews grant applications for academic research in solids processing. The 1985 article and Merrow's subsequent publications [3,4] should be required reading for industrial management and academics involved in particle technology. While Merrow's publication in a popular journal attracted great attention, some of the underlying technical and philosophical issues were concurrently identified in a chemical process scale-up book by Bisio and Kabel [5].

The 1985 Merrow article [1] reported that there was a strong relationship between plant feedstock type and the production rate (as a percentage of design rates) achieved by the end of the first year of operation. Fig. 2 illustrates the data. Liquid/gas feedstock plants performed better than

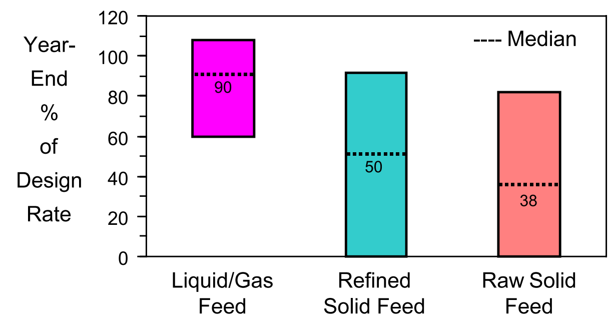

Fig. 2. Influence of feed material on the performance of new plants. Note that some plants produced no product in their first year, and all may have contained some new technology (from Merrow [1]).

refined solid feedstock plants, which in turn were better than raw solid feedstock plants. The latter plants achieved less than 40% of capacity in their first year. This topic was revisited by Merrow in 2000 [4] using a much larger, more recent database (508 plants, 1996–1998). The trends (Fig. 3) were the same, although performance across various types of plants was generally better, particularly for raw solid feedstock plants, which rose to 77%. However, the more recent plants may have contained less new technology than the pioneering plants in the first study. Merrow reports on the adverse effect that new technology has on plant operability [1,3,4] and demonstrates a strong statistical relationship between the number of process steps with new technology, the starting feedstock type and the startup time and production rates for new plants.

The effect of new process steps on start-up times is frequently underestimated, as shown in Fig. 4 [3]. While plant operators may allow extra time to start up one new process step they tend not to allow multiple units of time for processes with multiple new steps, believing that the start-up issues can be addressed concurrently. This reflects some lack of understanding of the nature of particle processes, in which the performance of each stage of the process is determined by the preceding one. Plant processing steps must be started

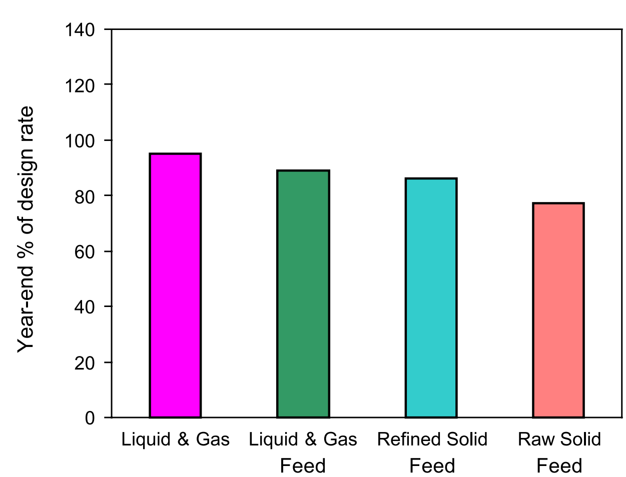

Fig. 3. Performance of new plants as function of feed material. Plot depicts median results (from Merrow [4]). Presence or absence of new technology in the plants is not specified.