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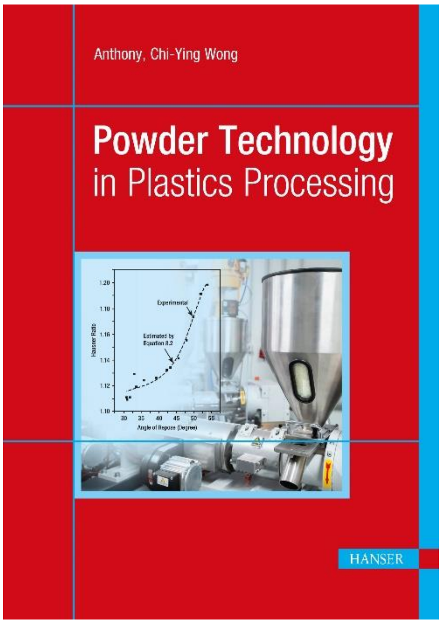

Sample Pages

Powder Technology in Plastics Processing

Anthony and Chi-Ying Wong

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Preface

This book has arisen out of an experience I had in handling a complaint from a blown-film fabricator who had been purchasing a white masterbatch from a local color masterbatch manufacturer. On one occasion, the fabricator reported to the supplier that the last batch of the masterbatch he received did not have the expected performance and quality. The throughput of his blown film line and the overall physical properties of the linear low-density polyethylene film made were noticeably different, with all the operation settings and let down ratio remaining unchanged. After a series of thorough investigations, it was found that the problem was caused by the wider size distribution of the titanium dioxide present in the last batch of the white masterbatch when compared with those in previous batches. This is a typical example of the underappreciation of the importance of particulate solids handling in obtaining good product quality and process optimization, although it is the most elementary processing step in the plastics manufacturing industry. Therefore, this book aims to provide readers with a broad understanding of powder technology and the significance of particulate solid characteristics that are applicable to plastics manufacturing processes. The purpose of this book is to provide useful and practical information offering alternative approaches for engineers to answer questions commonly found in the industry. Hopefully, the discussions of the selected examples of research investigations may encourage readers to formulate further fundamental as well as applicational research studies on the inter- and intra-relationship between powder technology and plastics processing technology.

Not only does book writing require the author's determination and interest, but also the support and encouragement from people around them, including family members. I am no exception and would therefore very much like to thank my wife, Sue, and my sons, Darren and Jens, for their patience and understanding during the time I spent writing this book. I am in great debt to Ms. Octavia Wong for her superb endurance to read through this entire monograph, making important corrections and suggestions on my English especially during the busy and difficult time she has had with her own research studies. I am also grateful for Dr. Keith

Hotten's constructive comments on my English, which have been very useful. Sincere appreciation is extended to Professor Augustine Wong for spending the time to ensure the correctness of the mathematics involved in this book. Acknowledgement must be given to Mr. Peram Prasada Rao of TechnoBiz Communications Co. Ltd., Thailand, for his continuous kind encouragement, which has motivated me to complete this writing task. I would also like to express my utmost appreciation to the late Professor Derek Geldart and Professor Norman Harnby for their excellent supervision during the years of my research study at the University of Bradford, U.K. Their enthusiasm, attitudes, and logical approaches on research investigations, from start to end, have set a valuable template for me to follow. Last but not least, words cannot express the amount of appreciation I have for my parents, brothers, and sisters for their excellent support and encouragement given to me over all these years.

The Author

After having graduated from the University of Bradford, UK, with a B.Tech. (Hons.) degree in Chemical Engineering and a Ph.D. degree in Gas Fluidization of Cohesive Powders, Dr. Wong spent a few years of his early career with BASF and Exxon Chemical as a technical and marketing support in their plastics divisions. He later became an academic member in the Department of Industrial and Manufacturing Systems Engineering at The University of Hong Kong. After he left The University of Hong Kong, he joined a listed color masterbatch compounding company in Hong Kong as its vice-chairman, largely responsible for the company's market development, seeking global commercial opportunities, and carrying out research and development projects. He is currently the Market Coordinator – Asia Pacific of Badger Color Concentrates Inc., USA.

Besides his vast commercial experience in the global plastics industry, Dr. Wong has been actively carrying out research studies, with focuses on plastics processing technology (extrusion, in particular), rheological characteristics of polymers, biodegradable polymers, environmental engineering, and powder technology.

Contents

1 Introduction

All polymer processes share one straightforward objective—to convert raw materials to finished products. However, this branch of technology is not as simple as it seems.

Tadmor and Gogos [1] pointed out that polymer processing is a multi-discipline. It involves different science and engineering principles. A successful conversion from raw materials to finished products will depend on our understanding of these principles. They suggested a comprehensive conceptual structural breakdown of this technology (Figure 1.1) to illustrate the inter- and intra-relationship of all the major subjects involved in this discipline.

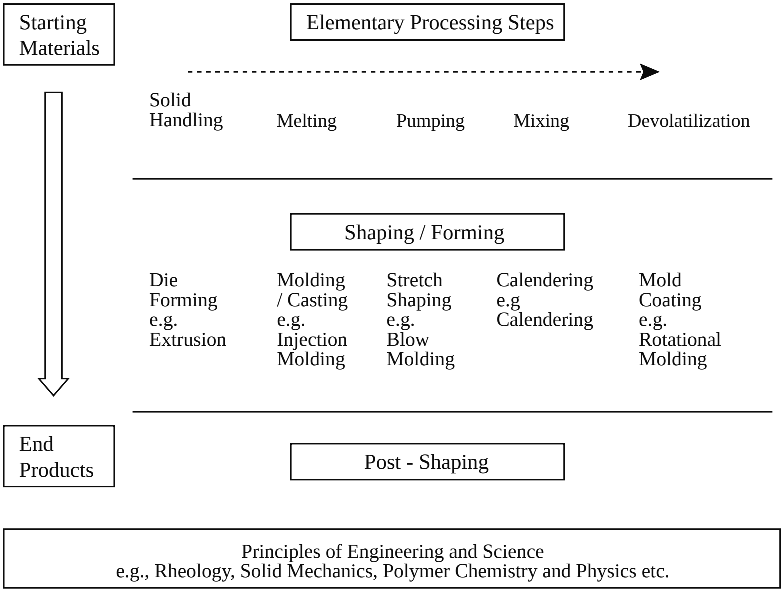

Figure 1.1 Conceptual structural breakdown of polymer processing suggested by Tadmor and Gogos [1]

It can be seen from Figure 1.1 that the conversion process was sequentially categorized into processes of:

elementary processing steps

shaping/forming methods

post-shaping

Common components within the category of elementary steps are *handling of particulate solids, melting, pressurization and pumping, mixing,* and *devolatilization and stripping,* regardless of the subsequent chosen shaping methods. Placing *handling of particulate solids* as the first required task in the elementary steps is well-justified, since almost all polymer processes start with raw materials in solid forms.

The comprehensiveness of the structural breakdown concept suggested by Tadmor and Gogos [1] is evident when tracking the "experience" that the solid raw materials have as soon as they are discharged into the hopper. Take blown film extrusion as an example. The homogenized solid raw materials will drop into the metal barrel as soon as they pass through the hopper throat. The solid materials will then be pushed (in the form of a solid plug) to the downstream by the combined effect of the rotation of the screw and the designed friction characteristics of the inner metal surfaces of the extruder. As the materials move forward, they will be compacted due to the decreasing clearance of the screw channels, causing the pressure to build up. This is a purposeful design to ensure that the compacted materials will be ready to melt at the compression/melting zone of the screw.

Melting of polymers is a slow process because polymers have low thermal conductivity and low thermal degradation. Thus, it is often a rate-determining processing step. Once molten polymer has accumulated inside the barrel, it will be continuously "pumped" by the rotating screw to travel further down. This transportation mechanism is different from the one that governs the transportation of the solid materials in the feeding zone of the screw. High pressure is generated instantaneously, which is needed for enhancing homogenization and effective subsequent shaping.

The processes of melting and pressurization may not necessarily be two distinct steps. There can be interactions between them. Therefore, as pointed out by Tadmor and Gogos [1], the two steps may occur simultaneously.

After pumping and pressurization, the next step is mixing. This is an important processing step because this is the last step in preparing the material for shaping. If the required mixing quality is not achieved at this mixing region, the quality of the finished products will inevitably be affected. It is worth mentioning that the purpose of this mixing step is not simply to obtain a physically well-homogenized mixture. It also serves the purpose of getting a mixture to have homogenized thermodynamic properties such as temperature.

If a polymeric system contains low molecular weight substances or substances of volatile properties, they must be expelled from the system prior to shaping once they have performed their expected functions. This practice forms the last component (i.e., *devolatilization and stripping*) in the suggested elementary steps.

Tadmor and Gogos [1] classified the different shaping methods adopted in the industry into *calendering and coating, die forming, mold coating, molding and casting,* and *stretch shaping.* These classifications were made based on the common required hardware and operation practice among the shaping methods. For example, the shaping devices in sheet extrusion, profile extrusion, pipe extrusion, etc., are all die-related. Therefore, they are grouped under the same classification of *die forming.*

Post-shaping essentially involves simple processes such as trimming, printing, punching, etc., which, in many cases, are relatively simpler and less complicated than the processes described above.

Figure 1.1 shows that elementary steps, shaping methods, and post-shaping processes are all firmly rooted in a number of science and engineering subjects. The principles of these subjects govern the conversion of raw materials to finished products. During the course of any conversion process, raw materials go through a series of phase changes, changing from solid to molten and back to solid again. These phase changes require a tremendous amount of work to be done on the system. For example, in the case of a single screw extruder running at a steady state, one rotation of the screw will need to perform all the elementary steps instantaneously. The efficiency of the screw in performing these designed functions greatly depends on our understanding of the principles of transport phenomena, rheological behavior, mixing characteristics, etc., and how these principles could be effectively applied in the hardware and process design considerations.

In the aviation industry, it is often said that a successful and smooth landing of a plane closely depends on how well the landing process is prepared beforehand. Similarly, a successful polymer manufacturing process is closely related to our understanding of the fundamental characteristics of the starting solid raw materials. The subsequent chapters of this book will systematically discuss these characteristics.

References

[1] Tadmor, Z. and Gogos, C.G., *Principles of Polymer Processing,* 2nd Ed. (2006), Wiley, New Jersey

A perfect mixture is a mixture in which the proportions of its components drawn from any locations in the mixture are exactly same as their proportions in the bulk before it is mixed. A random mixture is a mixture in which the probability of finding the proportion of a component at any locations in the mixture is the same, and is also equal to the proportion of that particle component in the bulk as a whole before it is mixed. Perfect mixtures are the ideal mixtures but they can never be achieved in reality. In fact, random mixtures have the best mixing quality that one could possibly obtain. If the probability of a particle component of a bulk is found to be greater at a certain place in the mixture, then the mixture is classified as a segregating mixture.

For a binary system, if the true proportions of the two particle components are unknown, their estimated values can be determined by measuring the proportions of the particle components from a number of samples taken at various locations in the mixture.

Assuming the total number of samples extracted from the mixture at different places is N, and the proportions of one particle component (i.e., y) is $y_1, y_2, y_3, \ldots, y_\mathrm{n}$, then the estimated mean proportion of the particle component of interest ($\overline{y}$) can be calculated using Equation 4.1, i.e.,

$$\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{4.1}$$

This simple estimate is not expected to give an answer close to the true mean proportion, μ, unless numerous samples are taken from the mixture for examination (i.e., $n \to \infty$). In this situation, $\overline{y}$ is more representative, but the examination procedure may not be at all practical.

The true mean proportion of one particle component in a binary mixture, μ, can be estimated if (a) mixture samples can be taken from a random mixture at any positions, and (b) the proportions of the particle component of interest in the mixture sample exhibit a normal distribution. It follows:

$$\mu \in \overline{y} \pm t_{n-1}\frac{s}{\sqrt{n}} \tag{4.2}$$

where

t_{n-1} = critical value of Student's t at degrees of freedom $n - 1$, which can be found from standard statistical tables

s = standard deviation of the sample proportion

This equation gives the possible values of μ with a specific level of certainty.

The standard deviation of the proportions of the sample mixture, s, may be used as an indication of the mixing quality. Williams [1] pointed out that the lower the standard deviation, the narrower spread in the compositions of samples and, thus, the better the mixing.

Index