Feeding Technology for Plastics Processing

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Preface

The purpose of this introductory book on feeding technology is to provide insight and useful information to the engineer or technologist who is new to the field of bulk materials feeding. The material presented will help when you must select feeding equipment and a control system for either a current process or a new installation.

As far as I know, there has been little in the way of books published on the subject since 1983 when Hendrik Colijn produced the summary volume entitled *Weighing and Proportioning of Bulk Solids*. Although the control systems described in his book are dated, to a significant extent, the textual material on feeder mechanics is quite appropriate. I reference his book throughout.

This book covers the basics in bulk materials handling, volumetric feeding, and gravimetric feeding of those materials. Significant time is devoted to feeder control systems and linking to supervisory computers used in modern processes. Some contents are based on my observations of many installations of feeding equipment. Other chapters present my views on how the user should go about selecting a vendor and the feeder installation issues that result once the equipment has been shipped from the vendor. The opinions expressed are my own and are based on more than 25 years of experience in the field of engineered, bulk feeding systems incorporating precision measurement and control. This experience included designing electronic circuits and systems and development of mechanical feeder components and assemblies and systems engineering. For the past 10 years, I have taught many of the concepts presented in this text.

Some discussion is also the result of study at the U.S. Patent and Trademark Office and the Library of Congress in Washington, D.C., plus a survey of a variety of related periodicals. I also share a little history about the development of the technologies that go into producing a gravimetric feeder. It is interesting to see how feeder technology and the underlying technology in electronics and software interact.

I thank Kevin Bowen, John Shoffner, and Lee Mayer, all from K-Tron America, for reading and commenting on sections of this book. However, any errors or omissions are mine alone. I also thank my wife, Sharon, for her understanding of my long hours at the computer.

I also thank my father and grandfather, Hugh and Frank Wilson, respectively, for their sharing of knowledge. Engineers both, they taught me the value of hard work and perseverance and the need for technology in this modern world.

David H. Wilson

Contents

1 Introduction

1.1 Purpose/Scope

The purpose of this book is to provide process engineers working in the field of plastics compounding with a basic knowledge of feeding concepts and of the various types of devices commonly used in feeding/proportioning operations. The focus of this book is on compounding as a continuous, rate-controlled processes, but the role of batching or end-point control in the production of plastic compounds is discussed briefly.

Discussions, about the various types of feeding machinery are as complete as possible throughout; the accent, however, is on machinery commonly used in the United States.

1.2 Introduction to Feeding

The concept of feeding is as old as the pharaohs and maybe older. Scooping grain for the pharaoh's table was a measure of quantity. While in those days, volumetric batch feeding was the standard—I am sure they didn't think of it in those terms—feeding technology has come a long way, and today, feeding as a technology is used in virtually every industry where bulk solids and/or liquids must be transported, combined, weighed, or metered. A highly complex technology for feeding was not necessary until the Industrial Revolution set into motion the idea of production lines or mass production. Josiah Wedgwood, originator of the famous Wedgwood china, really introduced the whole idea of a continuous production chain, changing forever how we produce product. Up until the 1960s, many industries continued to use batch processing, since the control issues were much less complex. However, with the advent of electronic systems, continuous production of many products became a reality. On the plastics side, it seems that the continuous compounding extruder was the marking point for an avalanche of activity in continuous processing that included feeders.

You now find sophisticated feeding systems in raw materials production, food processing, chemical and pharmaceutical processing, and of course plastics processing. Your grocers' shelves are filled with a vast selection of products that use feeding techniques in their manufacture. For example, a box of cake mix uses at least two processes that incorporate feeders. The blending of the powders that make the cake mix and the plastics production that makes the film bag inside are two common feeding processes. Even the production of the cardboard container uses simple feeding ideas for production of the inks and the raw materials that go into the base cardboard stock.

The basic concepts have, within the last few years progressed beyond the simple volumetric batch processing of old to sophisticated, computer-controlled continuous weighing and dosing systems that are used around the globe. It is also interesting to note that the processes used in snack food production bear an amazing resemblance to those used in compounding. So it is possible to move from industry to industry and apply the feeding concepts we suggest in this book. Certainly, selected attributes of feeding are more important in one application than in another, but the basic concepts hold.

The role of feeding in plastics production is critical if quality end products are to be produced. And while on the surface, the feeding of resins and additives seems simple enough, in fact, many complications can arise that can result in poor quality product or, worse, damage to processing machinery. There needs to be concern about the handling and precise metering of bulk solids. There are also concerns about all the interfaces to the process: electronic, mechanical, and human.

Every process engineer knows that demands on the process to produce a higher quality product—one that is reliably uniform at minimal cost—becomes more important each day. Feeders play a crucial role in assuring consistent product quality.

It is not a trivial task to design a feeding system to function over the wide variety of situations encountered in the processing world. Feeders have to meter a vast and diverse array of bulk solids, over widely changing and often difficult environmental conditions, at flow rates from a few grams per hour to many tons per hour under tight accuracy limits. Additionally, the control system complexity has grown as the need to interconnect into supervisory computers to enhance plantwide control becomes more necessary.

We will examine next what this has to do with plastics production, particularly plastics compounding.

1.3 Feeding and Compounding

The primary function of a feeder in a continuous compounding process is to accurately control the flow of a bulk solid or liquid material such that the resulting plastic compound meets predetermined quality standards with no waste attributed to improper performance on the part of the feeder. Careful specification of the feeding system's requirements, proper selection of ingredient feeders and associated material supply/handling equipment, correct installation, and thorough operator training combine to determine the success of the feeding system. Simply said, but difficult to do well.

Figure 1.1 shows a typical compounding extruder with four feeders, usually gravimetric (weighing) types, positioned at different locations along the barrel. The feeders control the introduction of a polymer resin, a color pigment, a filler such as talc, and a reinforcing agent such as strand fiberglass. This arrangement is quite common among compounders of plastic materials.

Feeders come in many shapes and sizes and exemplify many operating concepts. Careful selection and application result in the desired performance; casual or improper selection and application assure endless hours of frustration in the quest to produce a

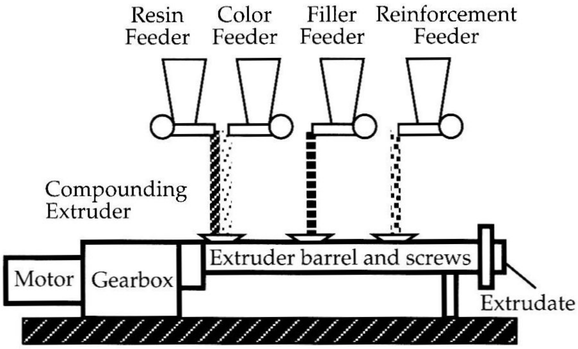

Figure 1.1 A typical compounding extruder incorporating four gravimetric feeders

high quality pellet. The basics of bulk material handing will be reviewed as progress is made in understanding the types of feeders, their control strategies, and their application.

Some of the complications that arise from compounding issues often relate to the difficult flow properties of the bulk solids to be metered. It seems that materials that are the most difficult to flow must be delivered at gram-per-hour rates, just the opposite of what the physics of bulk material flow would recommend. For example, often complex feeding solutions are required to meet the need to accurately discharge cohesive, TiO_2 at 1000 g/hr in a test lab extruder. How do you get this difficult flowing material to flow out of a small feeder with a small opening to the feed screws when the arching dimension of the bulk solid is more than 1 m? Some solutions will be suggested later in this book.

Do you have to meter recycled film into a process to reduce waste and improve cost effectiveness of production? Film handling is difficult at best. What about the need to feed blue pigment at 50 g/hr? Is this difficult? It certainly is when one considers all the potential flow problems that could occur between the feed bin and extruder opening. What effect will static electricity have on the reliable flow of the material? Static electricity can make the bulk solid cling to hopper walls, with little flow into the extruder.

There is often a need to meter liquids as well as bulk solids into the processing stream. The issue of control interactions becomes a focus. The question of metering liquids volumetrically versus using gravimetric techniques is most times left to the process engineer, and in a significant portion of cases, the cost factor weighs in favor of volumetric metering. Is volumetric metering always the best choice? The answer depends on a number of factors, including the simple fact of how reliably the volumetric system meters the liquid over a wide range of discharge conditions. Often, the process engineer's most serious mistake is to rely on the positive displacement pump to reliably and accurately control the discharge by velocity control only, in the absence of any type of flow feedback. A poor decision in this writer's opinion. The control system becomes more complex, therefore more expensive, when flow feedback is applied. In food processing, for example, process engineers make significant use of gravimetric control for liquid addition.

These complexities suggest that each material being used must be subjected to very thoughtful design considerations so that all precautions can be taken to ensure the expected performance. This would suggest a need to thoroughly understand the environment in which the feeder works and how that environment will affect the flow of bulk solids.

Compounders often are required to change bulk materials to meet differing formulations on a daily basis or even more frequently. This is important and unique processing difference from other industries that use feeding equipment. For feeder suppliers, the challenge becomes one of how to design feeders to meter a wide variety of bulk materials at widely varying setpoints and permit rapid changeover and start-up in the revised process scheme. In later chapters, we will see what vendors have done to try to logically deal with this problem.

Another consideration related to system design regards the linkage of feeder controls with the extruder control system. Sometimes, either extruder velocity feedback or die pressure feedback to the feeder rate control system is used to stabilize or maximize extruder output. More often, operators set the feeder flow rates based on extruder operating conditions. Additionally, data input and data viewing are incorporated within the extruder control system.

A point here about servicing feeder systems. In the writer's opinion, there should always be some type of vendor-provided user interface to the feeder system to permit simple feeder setup, maintenance, and diagnosis of feeder problems. Don't rely on doing those tasks at the extruder control center. It is not cost effective to implement all the data screens necessary to evoke such activity. Additionally, don't try to save money by eliminating motor velocity feedback on a feeder, even when the control system may not need this information for control purposes. Having actual motor velocity data available when diagnosing a feeder problem can be invaluable, and using such measurements for problem identification and correction will pay back the investment the first time the need to review them arises.

1.4 Foundation Technologies

Like most specialized technologies, feeding is founded on more basic technologies. It is a composite technology, presently drawing as needed from the three key underlying engineering technologies. To illustrate these relationships, consider the so-called feeding technology triangle (Fig. 1.2), which presents a pictorial view of the links between the different disciplines involved in designing and using a feeder. Like the three legs of a stool, the corners of the feeding technology triangle represent the three core disciplines that support and form the basis of bulk material feeding technology: bulk solids engineering, electronics and controls engineering, and mechanical engineering. The sides of the triangle represent the connections between these core disciplines—connections that are first made by the feeder manufacturer in designing and developing a feeder and are only completed only when a feeding system is successfully operating in a process application. Failure of any element in the feeding technology triangle destroys the effectiveness of the feeder system as a whole.

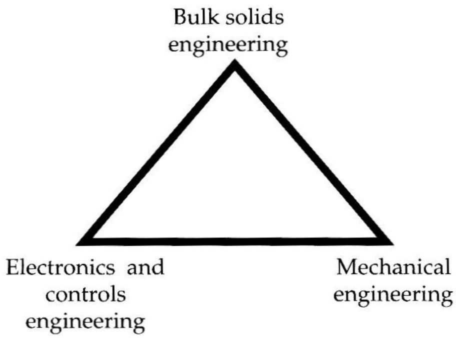

Figure 1.2 The feeding technology triangle

Since bulk solids engineering tends to be looked on as an art by those not skilled in the field, and since feeder selection must be based on how well that device can control the flow of the bulk solid in question, it is important to initially focus on this topic. Since any feeder's basic design must accommodate the broadest feasible range of materials, the feeder manufacturer dedicates significant time and effort to the development of various design approaches to enable a given feeder to effectively control bulk materials whose flow and handling characteristics cover wide spectrum . These design measures primarily focus on developing a family of interchangeable metering screw designs, each tailored to reliable control a specific subrange of materials and rates (e.g., low rate floodable powders, midrate cohesive materials, high rate pellets). Other measures the feeder manufacturer employs include engineered feeder bin design, agitation, and possibly the integration of specialized flow aid devices.

The feeder user must understand the possible impact of a particular bulk solid on feeder performance. For example, if the material does not flow out of the bin above the feeder, the feeder will not deliver the material to the downstream process. If the flow is erratic from the feeder supply bin, feeder performance may be degraded because of a failure of the refill system to quickly refill the feeder bin in the case of a loss-in-weight feeder. The same situation can cause erratic control from a weigh belt feeder because of insufficient or irregular supply. The mechanical design of the feeder and supporting bins and hoppers is of prime concern, since each is influenced by the bulk material that passes through it. Each influences the flow of the bulk solid. With either volumetric or gravimetric feeder applications, knowing the flow properties of the bulk solid plays a critical role in the success of the installation.

Since many gravimetric feeders require sophisticated controls, many engineers focus their time and attention on electronics and controls engineering. These control systems may be linked to process computers for supervision. The majority of engineering time is spent on elecronics design, as designers strive to optimize equipment performance by the implementation of improved algorithms and interfaces. In most modern feeder controllers, these algorithms are implemented by software running on dedicated microcomputers using embedded real-time operating systems. Since normally, electronic hardware and the associated software can be easily modified, careful design by the feeder vendor permits wide-ranging flexibility in the application and use of these control systems. Merely changing software by plugging in a new chip can change the controller from one that governs a weigh belt feeder to one that runs a loss-in-weight batch process. The key to success is to incorporate a microprocessor of adequate computing power to handle the full range of possible functions. Also useful are modular electronics designs that permit convenient substitution of one chip's instructions or control scheme with another. Since no laborious, error-prone reprogramming is involved in the modular approach, software conflicts or other unexpected problems are typically avoided. In any case, the underlying operating system should be multitasking and so designed that an error in one code module will not result in the failure of the remaining system.

The electronics must be "hardened" to work in an industrial environment. Hardware should function reliably under conditions of significant power fluctuations and in an environment involving radiation due to radiofrequency or electromagnetic interference (RFI, EMI). Where possible, optical isolation of inputs and outputs to the feeder control system enhances immunity to these difficult environmental conditions. Additionally, while it may initially appear to be cost effective to use 'household' devices such as common PCs to run a process, this practice typically is not advisable because the severity of the operating environment in most processing plants may cause operational problems. Producers of programmable logic controllers (PLCs) have set the standard for hardware robustness for industrial plants. Feeder vendors should follow their lead.

The mechanical engineering aspects of feeder design include the design and manufacturing of gearboxes, metering devices, and in the case of gravimetric feeders, the weighing system. The metering device must handle the bulk solid material reliably and predictably. The design and its execution must be robust, but in the case of gravimetric loss-in-weight feeders, not overly so, since the feeder is also being weighed. But in any case, failure of mechanical systems should not be tolerated in normal operating conditions.

The weighing system normally combines the disciplines of mechanics and of electronics, since most modern feeder weighing systems employ electronics in the control scheme. The mechanical structure of modern weighing systems, whether the electrical output is analog or digital, is sophisticated, since high accuracy and long-term performance in an environment of vibration and shock must be reliably maintained. Weighing measurement requires a load sensor of some type, a transducer that typically converts the weight force into an equivalent electrical signal. The load cell may weigh directly (resulting in a one-to-one correspondence between the load to be measured and the force applied to the transducer), or it may be part of a scale system. In a scale, the force of the applied load is mechanically reduced by a lever before application to the weight transducer in order to "scale" the load to fit within the transducer's operating range. Additionally, a scale provides load stabilization and overload protection. The mechanical scale must do these tasks without corrupting the load measurement made by the transducer.

The process engineer should think of a feeder as a part of a feeding system. A key element in systems thinking is the role of the installation and operating environment in the success of the operating process. This is where the user often has the greatest impact, since in most cases, the feeder vendor is not on site to pass judgment on the quality of the upstream equipment, the system interfaces, and the overall installation. Normally a feeder vendor finds out about such problems only during a plant visit occasioned by reported feeder problems. In fact, many process problems are not a result of a feeder failure but of related equipment problems such as poorly designed bins or chutes that direct bulk material throughout the process.

Additionally, a process environment with minimal vibration signatures and other disturbance-related effects can benefit the overall performance of any gravimetric feeder. The liberal use of shock isolators or other measures to prevent the transmission of ambient vibration to the feeder is a wise investment.

Finally, having personnel trained to operate and maintain the feeding equipment is like insurance. It provides peace of mind when any feeder-driven process is being run. The cost of training is oftentimes less than a few hours of downtime or a few hours of producing scrap. Thorough operator and maintenance training is simply the most cost-effective guarantee to the continued success of the compounding process.

1.5 Chapter Structure and Summary

Chapter 2 discusses the relationship between customer and feeder vendor that must exist to build a quality processing operation. Chapter 3 deals with feeder accuracy issues. Chapter 4 examines bulk material flow issues and the use of flow aids when gravity no longer helps. Chapter 5 studies the more commonly used volumetric bulk solids feeders. Chapter 6 analyzes weighing devices used for dynamic weighing applications. Chapter 7 reviews the gravimetric feeder and includes data on performance of open loop and closed loop volumetric feeders and gravimetric feeders. Chapter 8 presents feeder controls and a glimpse of where control is moving technologically. Chapter 9 gives a brief overview of batching processes. Chapter 10 suggests ways to implement supervisory control. Finally, Chapter 11examines the issues that face the user once the feeding equipment has been delivered to the plant site. The real problems of installation, start-up, operation, user training, and equipment servicing are presented and solutions suggested. Glossaries of symbols and terms are provided following Chapter 11.

We turn next to an examination of the key relationships that should exist in the buyer–vendor relationship to ensure long-term satisfactory operation of the purchased feeding system and continued, reliable support.

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2 Customer–Vendor Relationships

2.1 Purpose/Overview

This chapter suggests ways to help build a long-term relationship between you as a customer and the feeder vendor. Solid relationships improve the chance of maintaining your investment in a feeding system. First we discuss elements of what is hopefully a long-term, beneficial relationship. Let's examine the obligations and rights of each party, suggesting ways to get a sense, before you buy, of what you can expect from the vendor. Next, the process of preparing a specification is considered, and last we develop a decision model that is quite unique, the analytical hierarchical process, or AHP. A brief section devoted to those who work through architects and engineering companies, an arrangement that puts a middleman into the relationship.

When discussing relationships, one must consider the obligations and rights of each party. These linkages, are depicted in Fig. 2.1. Let us discuss the roles of each in the forthcoming partnership. I call it a partnership because any relationship, business or otherwise, will fail if one party takes advantage of the other. As time goes forward, if each party does what is agreed to, trust will grow and the partnership will strengthen for the benefit of both. When you have reviewed the following list of some services the customer is richly entitled to in the business relationship or partnership, you will undoubtedly have some ideas of your own to add.

2.2 Customer's Entitlements

The customer is entitled to expect at least the following from the vendor:

- Feeding machinery that works to specification
- Responsive service and support after the sale by the vendor
- Up-front honesty on delivery and pricing
- Fair pricing: honest value for product and services
- Clear upgrade paths for purchased equipment
- Significant warning on product obsolescence, with reasonable provisions for upgrade
- Truthful representation of the products and their capabilities
- Reasonable and fair terms and conditions of sale
- An established way of mediating solutions to any problems in a simple, fair manner
- Rapid and satisfactory response to field service problems
- Quick and satisfactory turn around on repairs