Handbook of Troubleshooting
Plastics Processes
Polymer Science and Plastics Engineering

The “Polymer Science and Plastics Engineering” series publishes both short and standard length monographs, textbooks, edited volumes, practical guides, and reference works related to all aspects of polymer science and plastics engineering including, but not limited to, renewable and synthetic polymer chemistry and physics, compositions (e.g. blends, composites, additives), processing, characterization, testing, design, and applications. The books will serve a variety of industries such as automotive, food packaging, medical, and plastics as well as academia.

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Preface

The goal of all troubleshooting operations is to restore the process to its original performance as quickly as possible with the least amount of cost. If the process is operational and producing a high level of off specification product, then the manufacturing costs can be very high. Restoring the line to its original performance quickly will reduce costs by eliminating some quality control operations and labor wasted in making product that is not fit for use, reducing resin consumption, eliminating recycle due to off specification product, and decreasing energy consumption. Moreover, if the line is inoperable due to the defect, the line downtime can be extremely costly, especially if the line is sold out. In this latter case, the goal would be to bring the line back to production operation as quickly as possible. Often, several different technical solutions will be possible. The best technical solution will be based on a combination of the cost of lost production, the time and cost to implement, machine owner acceptance, and the risk associated with the modified process.

This book provides a very practical guide to the troubleshooting of the most commonly used polymer processing operations, including injection molding, extrusion, films, blow molding, calendaring, lamination, and pultrusion. In every chapter, the process is described and the most common problems are discussed along with the root causes and potential technical solutions. Numerous case studies are provided that illustrate the troubleshooting process. Several additional chapters provide supporting information including statistics, economics, static electricity, and general troubleshooting. All chapters were written by expert troubleshooters with years of experience in their field.

The book was written for engineers and technologists that are performing troubleshooting operations on the plant floor. It provides the approach required for solving these types of problems quickly. The book provides key information for both the beginning and seasoned troubleshooters.

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The Dow Chemical Company
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Robert Slawska has more than 45 years’ experience in industrial blow molding. He founded Sterling Blow Molding Division in 1978. In 1994, he started his consulting firm, Proven Technology Inc. Mr. Slawska was awarded the Honored Service Member in 1998 from SPE. He received SPE’s Lifetime Achievement Award for Blow Molding in 2002. In March 2012, he became a member of The Plastics Pioneers Association.

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PART 1
TROUBLESHOOTING BASICS
The Economics of Troubleshooting Polymer Processing Systems

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Abstract
Polymer processing is a very cost competitive, but capital intensive endeavor. Most industrial operations consist of a sequence of complex mechanical, electric and thermal components, where ingredients are combined or transformed into higher value products to be sold to customers in the market. The equipment can experience problems that can negatively impact productivity and quality. Proper investments are required in expertise, hardware and software to enable a manufacturing organization to troubleshoot and resolve these problems in order for the business to remain viable in the global marketplace. This chapter examines the economics of key aspects of polymer processing troubleshooting in order to assist the reader in making decisions about how to plan for and make strategic investments in technology and expertise in order to maintain and optimize equipment performance and manufacturing productivity.

Keywords: Extrusion, compounding, economics, troubleshooting, uptime, yield, cost, safety, productivity, facilities, equipment, process, measurement, analysis

1.1 Introduction
The industrial practice of polymer processing has become very cost competitive while requiring a capital intensive set of operations that includes synthesis (polymerization), chemical modification, compounding, and forming or shaping steps. Most systems consist of a sequence of complex mechanical, electric and thermal components, where ingredients are combined or transformed into higher value products to be sold to customers in the market. In order to establish, grow or maintain a profitable business, manufacturing assets must operate at or near peak performance levels that deliver products with consistent properties and high quality. However, polymer processing equipment does experience many problems that can negatively impact productivity and quality. Proper investments are required in expertise, hardware and software to enable a manufacturing organization to troubleshoot and resolve these problems in order for the business to remain viable in the global marketplace.

This chapter examines the economics of polymer processing troubleshooting to assist the reader in making decisions about how to plan for and make strategic investments in
technology and expertise in order to maintain and optimize equipment performance and manufacturing productivity. Another objective is to show how it could cost more money or put a business at risk by avoiding the proper commitment to the resources required to identify the causes of processing problems and resolve them in a timely and economically viable way.

1.2 Economic Incentives and Necessities

Competitive industries like plastics processing demand high productivity in order to be profitable. Capital intensive manufacturing operations require high asset utilization. Key metrics can be used to quantify system economic performance and justify or track the costs of troubleshooting investments. The following measures are useful in determining the financial contribution of a process or set of resources allocated to that operation.

1. **Uptime** can be defined as the time that an asset is used to make a product that can be sold divided by the time that the asset is available to run:

   \[
   \% \text{Uptime} = \frac{t_{\text{Run}}}{t_{\text{Available}}} \times 100
   \]  

   The time available can include or exclude a number of normal production events. For example, annual plant shutdowns or routine, scheduled equipment overhauls may be excluded from the calculation. It is important that the uptime calculation be consistent over long times, so that performance changes can be compared with benchmarks. Depending on the process, uptime can range from 50 to over 95 percent. For example, a continuous polymerization unit can operate at uptimes from 90–95 percent. A small-lots custom compounding line may have an uptime of 50 to 65 percent. Catastrophic equipment problems, such as extruder screw and shaft breakage or motor drive failures have a serious impact on uptime. Material feed bridging, die hole freeze-off, die drips and plugged vacuum ports are examples of operational problems that also affect uptime.

2. **Yield** is the material produced that can be sold, divided by the total material processed. First-pass yield is the material that can be sold as a premium product meeting all specifications, divided by the total processed. Product that can be sold as second-grade or scrap may provide income, but first-pass yield is the goal-setting standard. Processes that are unstable or experience frequent upsets can produce significant off-spec products, adversely impacting yield. Uptime and yield are the two most common metrics used to assess manufacturing line productivity.

3. **Customer satisfaction and demand** is the most important measure of a product’s market value and viability. Poor quality can put a company out of business. Failure to meet demand could constrain growth and prompt a competitor to invest in a new asset to make the same or similar products that take market share.

4. **Labor cost** includes all resources allocated to a production line. This includes operators, engineers, chemists, mechanics and other skilled trades, contractors,
consultants, quality control or analytical laboratory staff, management and other overhead. Processes with frequent equipment failures can experience high labor costs.

5. **Energy cost** can be used to measure process efficiency. An extrusion line with poor temperature control may cost more to operate than one equipped with a modern computer system and well-tuned closed-loop controllers.

6. **Auxiliary or support equipment** includes the hardware or systems required to maintain process operations. Computers, software, instrumentation and testing tools may be needed in order to diagnose and resolve problems or prevent upsets or failure that impact uptime and yield.

7. **Waste generation and disposal** is another economic indicator of asset productivity and sustainability. Processes with frequent upsets or equipment problems can generate more waste that incurs a disposal and potential environmental cost. Excessive edge trim in a film line could increase the waste or material used as "re-work."

8. **Safety, health and environmental** events and impacts can be related to process problems and equipment failures. The cost of safety and environmental incidents or near misses can be tracked and correlated to process performance metrics, including uptime and yield. The failure to diagnose and resolve a process problem quickly could result in a serious injury or environmental release that could shut a line down for an indefinite period with potential legal consequences, not to mention the pain and suffering caused to individuals, families or the community.

9. **Capital productivity** can be calculated using uptime or yield data and the known fixed capital investment and depreciation costs. One may also include labor, energy and feedstock costs.

10. **Process capability** is a measure of how well an operation performs under the best conditions. It establishes valid uptime, yield and cost metrics to be compared over time. As problems arise, uptime, yield and costs will change and can be tracked over short and long time periods.

11. **Financial metrics and conventional accounting methods** can be applied to quantify manufacturing performance by combining sales or income with operating costs. Calculations that can be used include RONA (Return on Net Assets), ROI (Return on Investment) and other standard accounting practices that are used to manage costs and determine profitability. These methods will reflect the impact troubleshooting investments have on sales and costs.

These and other measures represent "hard" numbers that quantify process performance from a cost and benefit perspective. While minimizing production cost is critical in a competitive environment, uptime, yield and customer satisfaction ultimately determine if a company will thrive. In order to determine the investment needed for troubleshooting and its impact to the business, benchmark productivity values must be established. Uptime, yield and other baseline values can be estimated based on a manufacturing line's current or past performance. Daily, weekly or monthly calculations can be used to track short term trends, while quarterly or yearly measures may be used to quantify long term behavior. For some systems, short-term production throughput may be recorded and tracked (pounds/hour, parts/hour, feet/minute, rejects/hour and the like). Dynamic fluctuations and
running averages may be useful in identifying process problems and gauging the impact of troubleshooting efforts. Economic metrics can be normalized to account for changes in labor, materials, energy and other variable costs. Standard financial and statistical methods can be applied to analyze and compare long and short term performance estimates as compared to the baseline. These data can be used to establish a benchmark level, or to create measurable goals for an operation to strive for.

1.3 Troubleshooting Resources and Their Cost

A proper investment in troubleshooting expertise and equipment should be made in order to maintain a process operation at its designed capacity and benchmark uptime or first-pass yield, while minimizing the contributors to costs as outlined above. While troubleshooting infrastructure (expertise, hardware and software) can incur a significant cost to a business, it can easily pay for itself by solving problems quickly that might otherwise result in a catastrophic failure. State-of-the-art process equipment from established suppliers is usually equipped with sensors, electronic hardware and control system and diagnostic software that are critical tools for troubleshooting activities. Older manufacturing lines should be considered for replacement or upgrading with the latest diagnostic capabilities. The technical components of a typical extrusion compounding line will be used to exemplify how required expertise and capabilities can be identified.

1. Feed stock materials and additives (inputs). Reputable suppliers provide materials that consistently meet technical specifications. However, there are occasions where an off-spec lot of material may be delivered to a compounding plant. Furthermore, the supplier may change their process or their own sourcing, so that the material properties change slightly, but still meet product specifications. Your own formulation may change or replace one component with a material from a different supplier. Small changes in ingredients or formulation could result in problems that affect product quality, yield or process uptime. For example, two different high density polyethylene (HDPE) feed stocks may have the same melt flow index, but their molecular weight distributions may differ. A simple HDPE substitution could result in poor compounding performance as indicated by torque and pressure oscillations that could affect the time-temperature-stress history experienced by the formulation resulting in product property variability. Furthermore, customers might experience process upsets resulting in poor film quality or excess flash or mold deposit in injection molded parts. Thus, sufficient knowledge of polymers, additives and their interactions is required in order to diagnose material-related problems. Material suppliers may provide some information and expertise, but they do not know about your proprietary formulations and processing systems. Thus, sufficient expertise and infrastructure are needed in the fields of polymer chemistry and processing. A large company can support in-house expertise that can be leveraged across business units and product types. A toll manufacturer may know their technology, but they may require contract partners (suppliers, consultants, and engineering firms) to provide expertise for the materials used and the process methodology employed.