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Quality control of polymer production processes

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Abstract

For the polymer production industries, the competitive edge will come from the technology that excels in controlling the polymer properties in a consistent way over the entire plant and in maximizing the production performance while keeping safety regulations. Based on the experience in applying advanced process control and scheduling schemes to industrial polyolefin polymerization plants, the state of the art in quality control systems for providing the polymer production plant with an enlarged capacity for product discrimination and flexibility is reviewed. On-line soft-sensing and optimal grade changeover control problems are the main focus of this paper. A quality control system for polymer production plants, which integrates optimal control with on-line sensing and scheduling techniques, is discussed making reference to an application of a prototype system to an industrial plant.

Keywords: Polymer production plant; Quality control; On-line soft sensor; Grade changeover operation; Blending operation

1. Introduction

Use of polymers has been growing steadily in many industrial fields, such as automobile, food, apparel, electronics, etc. In the US, a fivefold growth of plastics in two decades (1974–1994) was reported [1]. It was attained by exploring new and various plastic applications. Polypropylene (PP) is now used for almost all automobiles. Soft drink bottles made of PET (polyethylene terephthalate) have almost completely superseded glass bottles, and PE (polyethylene) plastic bags have replaced the paper bags at grocery stores.

Consumers are learning that many plastic products are made from the same polymer. For example, PP used for a core material of instrumentation panel of cars is also used for car batteries, indoor–outdoor carpeting, and polyolefin intimate apparel. For each use, specific properties of the polymer are needed. In order to meet these demands, the polymer industries are producing many different grades of high quality polymers.

In recent years, the pressure from customers for greater grade variation and product diversification has been growing while specification of polymer quality becomes increasingly severe. For the future polymer industries, the competitive edge will come from a technology that excels in tailoring polymer properties and in controlling production plants toward maximizing product quality as well as production performance and safety.

In this paper, the state of the art in quality control systems for polymer production processes is discussed, based on the experience of joint university–industry projects in applying advanced process control and scheduling schemes to industrial polyolefin polymerization plants.

A significant amount of research has been done in the area of control, monitoring, and modeling of polymerization reactors, and excellent reviews have also been given by several researchers [2–6]. Because of the authors' bias and space limitation, this paper could not cover every important issue addressed in the past. On-line soft sensing and optimal grade changeover control are mainly focused on this paper.

One of the issues discussed throughout this paper is plant-wide total quality control with design of molecular structure at microscale to macroscale levels: The polymer production plant does not consist only of reactor(s). It consists of reactor(s), separator(s), dryer(s), extruder(s) and blending tank(s). Therefore, quality of the polymer is affected not only by reactors' operation conditions but also by extruding and blending operations. In addition, polymer properties are determined by

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low-order and high-order molecular structures of the polymer. Thus, to provide the production plant with an enlarged capacity for product discrimination and flexibility, the polymer properties should be controlled on each molecular structure level in a consistent way throughout processing history — from reactors to separation units, extruders, and to blending tanks. A scheme of quality control system for polymer production plants, which integrates optimal control with on-line sensing and scheduling techniques, is discussed making reference to an application of a prototype system to an industrial plant.

2. Polymer production plant

A highly simplified schematic diagram of a polymer production plant is illustrated in Fig. 1. In general, polymer production plants consist of a train of reactors in series, separation processes, extruders, and blending tanks. As Ogunnaike [7] described, neither a recycle loop of unreacted monomer nor blenders is required, making the operation very simple if environmental regulations, production cost and product quality are not considered. But, in reality, a train of reactors is used to produce layered products, and the separation units are installed to recycle the unreacted monomer in an attempt to meet various environmental regulations and to reduce the production cost. The blenders are also required to damp out product quality variability. Furthermore, to meet grade variation and product diversification without increasing equipment cost, it is not unusual that a plant produces as many as 10 grades or even more by changing its operating conditions. As a result, the plant becomes increasingly complex and the operation increasingly difficult.

Basic regulatory control of key process variables, such as temperature and flowrates is imperative, but this alone is not sufficient to produce various grades of high-quality polymer products at an economically attractive cost.

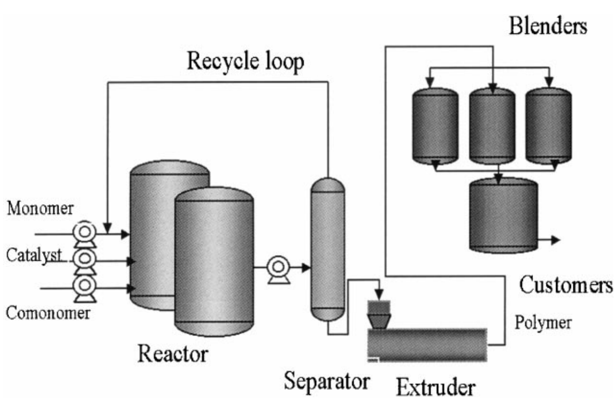

Fig. 1. Simplified schematic of polymer plant.

An overall view of a prospective control system for a polyolefin plant is illustrated in Fig. 2, soon after the specification of the polymer is given by the customers, polymer quality that the individual processing unit produces should be specified appropriately. Operating conditions are then determined for each unit to meet the specified quality. Taking plant stability into account, a production schedule is determined so as to meet the demand while keeping the inventory cost low. Following the determined schedule, safe and quick changeover operations are performed by a sophisticated control system.

3. Needs for quality modeling

Polymerization reaction engineering contributes greatly to modeling and understanding how the reactor operating conditions affect molecular properties, such as molecular weight distribution, composition distribution, and degree of chain branching, etc. [6]. Rheology plays an important role in bridging a gap between molecular properties and rheological properties, which are close to end-user quality.

Table 1 describes qualitative relationships between molecular properties and polymer properties as well as processability of the polymer [8]. As illustrated in Table 1 and Fig. 3, end-user properties depend strongly on the polymer low-order and high-order molecular structures as well as their distributed nature of variables (molecular weight distribution, etc.). For example, hardness of the polymer depends on polymer crystallinity that is determined by stereoregularity of polymer: a linear polymer with small side-groups is highly crystalline; a linear polymer with bulky but regular side-groups has low crystallinity; and a linear polymer with bulky and random side-groups is non-crystalline. Similarly, the morphological form of a HIPP polymer is often a key variable of end-user properties, and it depends on particle size distribution, polymer composition distribution and processing history in the extruder.

To determine the operating condition for each individual processing unit, it is indispensable to have deeper understandings about how the end user properties are affected by molecular structure, its distribution, and operating conditions of each processing units. The quantitative representation of the relationships is called the quality model. To construct a quality control system for polymerization plants, it is crucial to develop such quality models which can describe the relationships among end-user properties, polymer properties, their molecular structures, and processing history. Several attempts have been made to develop such models. However, there are many relationships yet to be described quantitatively.