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Real time measurement and control of viscosity for extrusion processes using recycled materials

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The aim of this paper is to develop a new generation of extruder control system for recycled materials which has ability to automatically maintain constant a polymer melt viscosity of mixed recycled polymers during extrusion, regardless of variations in the Melt Flow Index (MFI) of recycled mixed grade high density polyethylene (HDPE) feedstock. The variations in MFI are due to differences in the source of the recycled material used. The work describes how melt viscosity for specific extruder/die system is calculated in real time using the rheological properties of the materials, the pressure drop through the extruder die and the actual throughput measurements using a gravimetric loss-in-weight hopper feeder. A closed-loop controller is also developed to automatically regulate screw speed and barrel temperature profile to achieve constant viscosity and enable consistent processing of variable grade recycled HDPE materials. Such a system will improve processability of mixed MFI polymers may also reduce the risk of polymer melt degradation, reduce producing large volumes of scrap/waste and lead to improvement in product quality. The experimental results of real time viscosity measurement and control using a 38 mm single screw extruder with different recycled HDPEs with widely different MFIs are reported in this work.

1. Introduction

The large amount of disposable plastic bottles widely used makes it imperative for the development for recycling or reuse of these materials as they are not biodegradable and exhibit slow decomposition processes. Plastics recycling and reducing the volume of plastic waste going to landfill is an emotive subject, highly publicised by our increasing dependence on oil, fears over future supply-demand and concern for our environment. Social responsibility has encouraged the plastics industry to invest in technologies to minimise the disposal of plastic waste to landfill through recycling processes.

Recycling process of plastic bottles normally comprises of sorting, washing and pelletizing processes. Bottles are ground into flakes and the contamination of the flakes is removed in the washing process. The pelletizing process with mesh screening filters removes any further contamination of the flakes using an extruder. Despite considerable development in waste plastic sorting technology [1–4], the properties and quality of the recycled polymers are normally lower than those of the virgin material [5,6] and strongly dependent on the operating conditions [7].

During the extrusion process, the recycled polymers undergo a complex thermomechanical transformation, inducing complex rheological behaviour of recycled polymer melts. The processing conditions can have a major impact on the polymer as its molecular structure may undergo change as a result of chemical reactions (oxidation, cross-linking) taking place in the extruder, which are usually induced by high temperature and high shear stress conditions. The change in molecular structure brought about by degradation can significantly affect the melt flow properties and alter the physical and chemical properties of the recycled materials and the aesthetic properties of polymer products.

In comparison with melt temperature and pressure, melt viscosity is largely recognized as the most relevant indicator of melt quality because it is directly related to the aesthetic/dimensional properties of the melt and the molecular orientation relating to the functional properties of a polymeric extrudate [8,9]. With recycled plastic, the main issues for extrusion processes are the variations in viscosity or in MFI of the recycled polymer feedstock [10,11]. These variations of recycled plastic between batches of recycled materials are greater than for virgin materials due to differences in the physical properties of the source of waste plastic materials used. As a result, it is difficult to process these into good quality products without incurring high scrap levels, for instance, if the viscosity is

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too high, the extruded products will collapse on exit from the extruder die, however if it is too low, the material will not flow properly through the die resulting clogging at the die. Both result in extrusion processes downtime, material wastage through the generation of scrap and the variable performance with regard to product quality. Real time monitoring and control of the melt viscosity in the polymer flow are therefore desirable to achieve high product quality in the extrusion processes.

Several types of melt viscosity measurement techniques have been developed recently including off-line laboratory capillary rheometry, torsional viscometry [12], on-line side-stream [13], as well as methods using shear stress sensor techniques [14]. However there have been few reports on the application of real time viscosity control in extrusion processes and this is probably due to design complexity, the development of meaningful control strategies, measurement accuracy and high cost. An alternative approach which has also been reported, is to determine the melt viscosity, based on modelling techniques. These methods involve the estimation of the melt viscosity on the basis of system inputs, such as temperature and screw speed [8]. Nonlinear modelling methods, using neural networks [15,16] have demonstrated the ability of producing adequate nonlinear dynamic inferential models for polymer viscosity. The drawbacks of these methods are that many parameters need to be tuned and lack of the insight of the process. The development of combining mechanistic and parametric data in grey box modelling techniques, associated with intelligent algorithms such as fuzzy logic, neural network and genetic algorithms, have also been reported [17–20]. However, this research is only at a modelling stage, and there has been no reports on the application of these models to real time control systems.

Feedback control techniques for extrusion processes have been described in several reports. In Refs. [21], a conventional PID controller was applied to maintain constant temperature along the barrel and constant pressure at the extruder exit. A fuzzy logic modified PID controller for viscosity control was developed in Refs. [22,23], however, only virgin LDPE material and low extruder speeds were investigated in this report.

This paper describes the introduction of a total integration system, including viscosity measurement and control for recycled polymers during the extrusion processes, using an automatic closed-loop control technology. This innovation will enable constant melt viscosity to be maintained during the extrusion of mixed grade polymers, regardless of variations in MFI of feed materials and enable consistent processing of variable grade recycled plastic. All the experiments described in this paper were carried out on a 38 mm single screw extruder with slit die. The extrusion system was also fitted with a gravimetric loss-in-weight hopper feeder for real time throughput measurement. Using this device, the melt viscosity can be calculated online simply from the measurement of throughput (kgs/hr) and the pressure drop through the die using the geometric dimensions of the extruder/die arrangement [24]. Both the screw speed and the first three barrel temperatures zones are used as control variables and automatically regulated with respect to variations in the melt viscosity of feed materials during the extrusion process, by the novel control system.

The paper is organized as follows. Section 2 presents the experimental setup for viscosity control system. This includes the use of the loss-in-weight hopper feedersystem to monitor the throughput of material consumption during the process. The calculation of viscosity in real time based on throughput and pressure drop through the die compared with offline viscosity measurement using laboratory rheometry technique is shown in Section 3. The variation in viscosity of recycled polymers at a fixed extruder screw speed using open loop control is reported and discussed in this section. In Section 4, the closed-loop control

Fig. 1. Experimental apparatus.

Fig. 2. Loss-in-weight hopper.