Melting Mechanism of a Starved-Fed Single-Screw Extruder for Calcium Carbonate Filled Polyethylene

M. R. THOMPSON*, G. DONOIAN, *and* J. P. CHRISTIANO

Davis-Standard Corporation, Technical Center
Pawcatuck, Connecticut 06379

A study of starved-fed single screw extrusion was initiated to understand the relation between its distinctive melting mechanism and the improved mixing capabilities attained during compounding of a calcium carbonate filler into HDPE. Experiments were carried out in a 63.5 mm single screw extruder, examining the effect of degree of starvation on a conventional and barrier feed screw. Interest was focused on the mixing/melting mechanism of starved-fed solids-conveying as it affects the size and number of filler agglomerates observed in the extrudate. The melting performance of both feed screws was examined using pressure and temperature measurements down the screw length as well as direct inspection of the polymer in the screw channel via rapid screw cooling. Both screws showed improved mixing quality with increased starvation.

INTRODUCTION

Economical and technological forces are extending and diversifying the application of plastics in modern products and consequently requiring increased usage of solid and liquid additives (1, 2). Typically, several additives are combined together with a plastic for a specific process, with choices ranging from a multitude of categories including fillers, plasticizers, reinforcing agents, lubricants, blowing agents, flame retardants, stabilizers, etc. The effectiveness of any of these additives within an intended product depends on their homogeneous dispersion within the polymer matrix. Thus, the efficiency of mixing becomes a defining issue, as most of these additives are immiscible within a polymer. To enhance the capabilities of single-screw extruders for more effective mixing, vented extruders are being requested with longer L/D ratios and more sophisticated mixing devices are being introduced to the industry. The purpose of these mixing devices is to introduce greater-than-linear mixing to the otherwise linear mixing inherent of helix-in-a-helix flow within a single screw extruder. In the case of mixing solid additives into a polymer, it has been noted by several authors (2–4) that once agglomerates are formed, it is unlikely that the mixing behavior of an extruder can overcome their binding forces, even within an intensive mixing zone. Gale (3) stated that the most appropriate means of avoiding agglomerates in the product of an extruder was to prevent their formation. Observations made in experimental trials by the present authors, showed that both barrier and conventional screws provided a significant reduction in the size and presence of powdered agglomerates when the extruder was starved even by a small amount (5–20% starvation). The present work attempts to understand the mixing/melting mechanism of starved-fed solids-conveying and the manner by which powder agglomerates are reduced in size and number.

General understanding of the mechanisms for solids-conveying and melting in a flood fed plasticating extruder has been well developed since the early experimental work of Maddock (5) and Street (6). Solids-conveying prior to the onset of melting has been determined to be frictional force dependent, changing to a viscous shear dependency with the beginning of a melt film (7, 8). The model of Darnell and Mol (9) represents one extreme of the transition taken by the solid bed, attempting to explain the conveying of solids in the absence of melt with the assumption of a constant bed velocity. Chung (8) modeled the opposite extreme, looking at a solid bed reliant on viscous shear forces for movement. The melt film which forms adjacent to the barrel surface generally maintains its thickness by balancing melting rate and drag-induced flow, accumulating as a melt pool on the advancing-side of the flight once the pressure at this location exceeds the yield forces of the compact solid bed. The pressure measured over the solid bed is an indicator of the shear stresses and hence indicates the contribution of viscous heating to the melting rate (10). In studies on the formation of agglomerates with calcium carbonate ($CaCO_3$), Gale (1) observed from screw push-outs that in the early stages of melting, the powdered additive

*To whom correspondence should be addressed.