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In-line determination of plasticized wheat starch viscoelastic behavior: impact of processing

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Abstract

In-line slit and capillary die viscometers were specially designed to study the viscoelastic behavior of plasticized wheat starch under low-hydrated conditions. A wide range of shear rates could be obtained by the use of different die geometries. The effects of temperature (110–150 °C), glycerol (10–35%) and moisture contents (0–20%) were studied. The influence of the specific mechanical energy (SME) (100–650 kWh/t) applied to the products was also accounted for. In the range of extrusion conditions, the viscosity data of starch melts followed the classical power-law behavior. A general rheological model was derived from experimental results. Discrepancies of viscosity values found between in-line viscometry results and those of a pre-shearing rheometer, the Rhéoplast[®], could be explained by carefully taking into account the temperature and SME conditions. The impact of processing in regards to the starch transformation was investigated through intrinsic viscosity measurements and thermal analysis. The elastic properties of starch melts were also assessed through the analysis of entrance and exit pressures data.

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1. Introduction

In the past decade, the use of starch resources in non-food applications has considerably developed in order to find substitutes to petroleum-based plastics, because of growing environmental issues. The potential development of starch-based plastics involves a better understanding of the starch transformation using conventional polymer processing operations (Doane, 1992). In addition, the knowledge of the viscous behavior of low-moisture molten starch is required to better control the quality of extruded products as well as to determine optimal processing conditions.

The extrusion and viscous behavior of molten starch is known to depend on temperature, moisture content and thermomechanical treatment (McMaster, Senouci, & Smith, 1987; Padmanabhan & Bhattacharya 1991; Parker, Ollett, Lai-Fook, & Smith, 1990a; Parker, Ollett, & Smith, 1990b). Viscosity data and rheological models that take into account

these variables have been reported in literature. Table 1 summarizes the main rheological studies performed on starch, including the measurement technique and models used. They all report a thermoplastic behavior of low hydrated starch, within a two orders of magnitude shear-rate range, with an Arrhenius dependence on temperature and similar for moisture content. Conversely, structural modifications of starch, also affecting the viscosity of product, is reflected differently by specific mechanical energy (SME), the screw speed (N), or even the extruder barrel pressure (P_b), which depend on the machine characteristics (see equations of Table 1). This discrepancy underlines the need for ascertaining the dependence of starch melt viscosity upon structural factors or variables directly involved in its transformation. Some authors have introduced terms relating the modification of starch, such as conversion, degree of transformation, or extent of degradation (Barrès, Vergnes, Tayeb, & Della Valle, 1990; Colonna, Tayeb, & Mercier, 1989; Davidson, Paton, Diosady, & Larocque, 1984a; Davidson, Paton, Diosady, & Rubin, 1984b; Zheng & Wang, 1994). Lai and Kokini (1990) studied the rheological

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