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Thermo-mechanical processing of sugar beet pulp. I.Twin-screw extrusion process

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Abstract

Sugar beet pulp (SBP) is the raffinate of sugar extraction. Composed of empty vegetal cells, three quarters of it consist of polysaccharides. As it is cheap and produced in great quantities SBP is a potential raw material for industrial applications other than cattle feeding. Twin-screw extrusion modified its structure and destructuring level depended on the specific mechanical energy provided (SME). By gradually increasing this energy, the rate of soluble matter increased, cell structure was progressively destroyed and SBP rheological behaviour was modified. For an SME of 745 W h kg^{-1}, SBP examined through a scanning electron microscope showed a structure similar to that of a composite formed by a continued matrix consisting mainly of pectin and hemicelluloses filled with cellulose microfibres. Plasticized SBP was then formed by injection-molding. Thus treated, SBP becomes a cheap alternative to the use of thermoplastic starch for the production of biodegradable materials.

Keywords: Twin-screw extrusion; Rheology; Thermoplastic; Injection-molding

1. Introduction

A third of the world production of sugar comes from sugar beet (*Beta vulgaris*). One ton of sugar beet (saccharine content 16%) provides a dried weight of around 130 kg of sugar and 50 kg of a by-product, sugar beet pulp (SBP). Pulp output in Europe was more than 6 Mt in 2002 and its price after dehydration was approximately 0.1 € per kg^{-1} (CGB, 2000).

The industrial sugar extraction process consists of a counter-current hot water circulation which preserves cell structure and avoids co-extraction of parietal compounds. Thus, sugar beet pulp is made of vegetal cells drained of their vacuolar sap, but whose membranes have not been affected (Dinand, Chanzy, & Vignon, 1996). These cell walls are primary as harvesting takes place as soon as the tuber reaches its maximum size and weight. SBP consists mainly of cell wall polysaccharides in almost equal proportions as compared to the dry matter, that is approximately 25% cellulose, 25% hemicellulose and 25% pectin. It also contains a small quantity of lignin (Okojie & Sargent, 1990). More precisely, the cellulose in sugar beet cell walls is made of 2–4 nm in diameter fibril arrangements (Dinand et al., 1996) of low crystallisation level (Heux, Dinand, & Vignon, 1999) embedded in a matrix consisting of arabinans and arabinogalactans (Sun & Hughes, 1999) linked by covalent bonds to highly methylated and acetylated pectic chains.

Due to its composition, SBP is considered as forage or as foodstuffs (Bach Knudsen, 1997), and is therefore used only as a food complement to animal feed. However because of high-cost dehydration and low protein content, alternative uses have to be investigated to avoid the waste of a large amount of the production. Enhancing the value of the extracts was considered first: food fibres (Michel, Thibault, & Barry, 1988), cellulose microfibrils (Dinand, Chanzy, & Vignon, 1999; Togrul & Arslan, 2003), pectins (Oosterveld, Pol, Beldman, & Voragen, 2001; Turquois, Rinaudo, Taravel, & Heyraud, 1999) or ferulic acid

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(Mathew & Abraham, 2004; Micard, Renard, & Thibault, 1994). Raw SBP was also used as a cultivation substrate (Yoo & Harcum, 1999), for divalent cations complexation (Dronnet, Renard, Axelos, & Thibault, 1997; Reddad et al., 2002), as a source of polyol for the production of urethanes and polyurethanes (Pavier & Gandini, 2000a, 2000b) or as a source of fibre in the composition of biodegradable materials (Baar, Gebel, Imhof, & Mihalik, 1997; Turbaux, 1997) or for paper manufacture (Wong & Bregola, 1997). Structural modification of SBP was only considered from two different points of view: chemical or enzymatic hydrolysis for the production of a paste to be used in the manufacture of packaging (Berghofer, Grzeskowiak, Mundlinger, Schleining, & Zenz, 1992) and parietal polysaccharides solubilization by extrusion-cooking to improve its nutritional properties (Ralet, Thibault, & DellaValle, 1991).

The aim of the first part of this work is to demonstrate that twin-screw extrusion in extreme conditions makes it possible to break sugar beet cell structure while avoiding thermal degradation. This process liberates the non cellulosic cell wall polysaccharides from their native organization and SBP acquires some interesting thermoplastic properties and can be injection-molded. The obtained material mechanical properties are tested.

2. Materials and methods

2.1. Material

The sugar beet pulp (DM = 89.9%) originated at the Cagny site (France). Before being processed it was coarsely grinded through a 6 mm grid.

2.2. Extrusion

A Clextral BC45 co-rotating twin screw extruder (Firminy, France) was used. Its barrel was divided into seven 20 cm sections for a total length of 1.4 m. It could be fitted with a converging 10 mm diameter die in at its end, over which was placed a demultiplication plate bored by eight 2 mm diameter holes and holding a granulating blade. The profile of the screw was of variable screw elements with two sections of mechanical constraint (Fig. 1). The screw elements used in Section 1 were chosen to help water impregnation and to apply a first mechanical stress. They were some blocks of either kneading disks (Mal0) or kneading paddles (Mal2) orientated one from another with variable angles or some notched wheels (MEL). The length of this section was always 100 mm. The second zone was dedicated to high shear treatment under compression. The screw elements used were either some twin lead reverse screws (C_2FC) or some single lead reverse screws (C_1FC) of a length of 50 mm. The rest of the screw configuration was made of double lead screws with a pitch of 33 or 25 mm. A typical screw configuration is shown on Fig. 1.

The electrical power of the motor was measured continuously and allowed the specific mechanical energy to be calculated (N'Diaye & Rigal, 2000). Barrel in Section 2 and die were equipped with pressure and temperature sensors (Fig. 1). The temperature of the barrel was programmed at 25/25/70/70/70/70/70 °C. It increases by self-overheating in stress areas to an equilibrium temperature depending on the operating parameters. The amount of water introduced was expressed by the L/S mass ratio of the water input flow rate to the dry matter input flow rate.

2.3. Solubility

Three samples of each extrudate of approximately 3 g were dried and weighed. They were then soaked in 50 ml of distilled water at 25 °C. Suspensions were stirred regularly in a discontinuous manner during 24 h, then filtered. Solid residues were then dried and weighed. The difference between the initial mass and the final mass compared to the initial mass led to the determination of the content of soluble matter.

2.4. Colorimetry

Samples were finely grinded through a 1 mm grid before analysis on a Minolta CM-508i spectrocolorimeter (Ramsey, USA) in the referential $L^*a^*b^*$.

2.5. Adsorption isotherms

Samples were dried for 15 days at 60 °C in a vacuum desiccator before being placed in the hermetic containers containing the saturated saline solutions which set the moisture level of the upper part of the container (Rouilly, Orliac, Silvestre, & Rigal, 2001). Equilibrium was reached when sample mass did not vary more that 1% in 24 h. Their

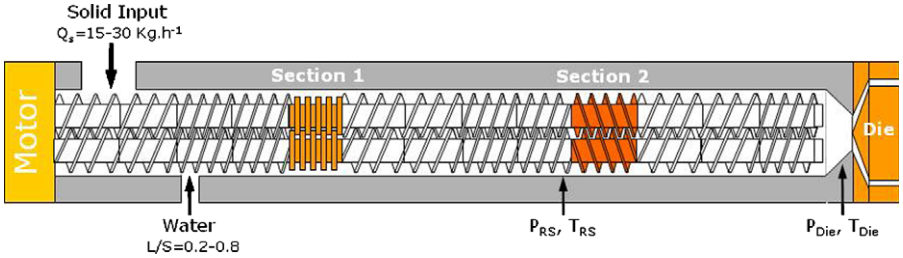

Fig. 1. Schematic representation of the twin-screw extruder configuration.