

Effects of Dynamic Pulsed-Pressure Processing on Starches and Fibers

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ABSTRACT

Significant changes in moisture properties, density, shifts in melting patterns, and reordering of molecules were observed as the result of dynamic pulsed-pressure treatment. Corn starch, modified corn starch, cellulose, or wheat bran were made into slurries (12-20% T.S.) and fed by gravity into the pressure chamber. Pulsed pressure treatment was applied at 120 cycles/min, within-chamber pressure treatment was 1.0 sec. Dynamic pulse pressure was included at 414 or 620 MPA respectively in the chamber at a slurry flow rate of 15 L/h. Pressure packing of molecules resulted in increases in density and reduction in water-holding capacity in cellulose fiber with a 35% reduction in water-holding capacity, a significant change ($P < 0.05$), which will allow for increasing the quantity of cellulose fiber incorporated into foods. Peak melt points were reduced, with subsequent increases in enthalpic energy.

INTRODUCTION

High pressure processing of foods has been reported over 100 years ago. Hite (1899) of the State of Virginia Agriculture Experiment Station reported on the effects of high pressure on milk preservation. The effect of pressure on biomolecules and biopolymers vary, depending on physical properties. Effects of high pressure have been reported on microorganisms (Hite et al., 1914; Hoover et al., 1989), fruits and vegetables (Cruess, 1924), gel formation in proteins (Morild, 1981), and on physical attributes (Farr, 1990).

The effect of pressure varies according to type of material and the chemical composition. With simple elements or compounds (carbon graphite), the effect of pressure and temperature is linear, however, for foods and biomolecules, the effect of pressure and temperature is nonlinear (Heremas, 1995). Reported effects of high hydrostatic pressure on physical characteristics of biomolecules include increase in density, due to molecular packing, shifts in peak melting points, from thermal analysis, and changes in textural and moisture properties (Farr, 1990).

Hydrostatic pressure with large time domain (30-180 min), has been the widely practiced mode of pressure processing. This process is time-dependent, and not very efficient for food processing where bulk processing is the norm. Hydrostatic pressure could be classified as low (<400 MPa), high (>600 MPa) and ultra high pressure (>600 MPa). Recently, practices such as sinusoidal and step-pressure processing are being practiced to improve the bulk of products processed by high pressure. The objective of this work was to investigate dynamic pulsed-pressure processing and to evaluate the effect of dynamic-pulsed-pressure-processing on starches and fibers.

MATERIALS & METHODS

corn starch, modified corn starch, wheat bran fiber and cellulose fiber were investigated. materials were received from commercial processors: stabilized white wheat bran (Canadian

harvest, St. Thomas, Ontario); powdered cellulose (BH300[®], International Filler Corp., N. Tonawanda, NY); pure dent corn starch (Grain Processing Corp., Muscatine, IA); and modified waxy maize starch (Capsul[®], National Starch & Chemical Co., Bridgewater, NJ). The materials were prepared as outlined in Fig. 1. The materials were dissolved in distilled water to make a slurry (20% solids, for starches and 12% solids for fibers. The slurry was then heated and maintained at the desired conditions of temperature 25 or 70°C), or acidity (pH 5.0±0.2). Control samples were removed from the slurry stream before pressure processing. The slurry was gravity fed into the high pressure chamber and processed at either 414 MPa (high pressure) or 620 MPa (ultra high pressure, UHP). At each pressure setting, the material was either processed once (one pass) or multiple times (five passes), to determine the effect of multiple passes. The processed slurry was frozen (-20°C) in stainless steel plates for 18 hr. The frozen slurry was dried in a freeze cabinet dryer (NYECO VAC Dryer, NY) for 48h. The free flowing powders recovered contained less than 8% moisture.

Moisture was determined under vacuum at 100°C (AOAC, 1997). Bulk density was determined with an air pycnometer (Horiba Instruments Inc., Model VM 100, Irvine, CA). Water-holding

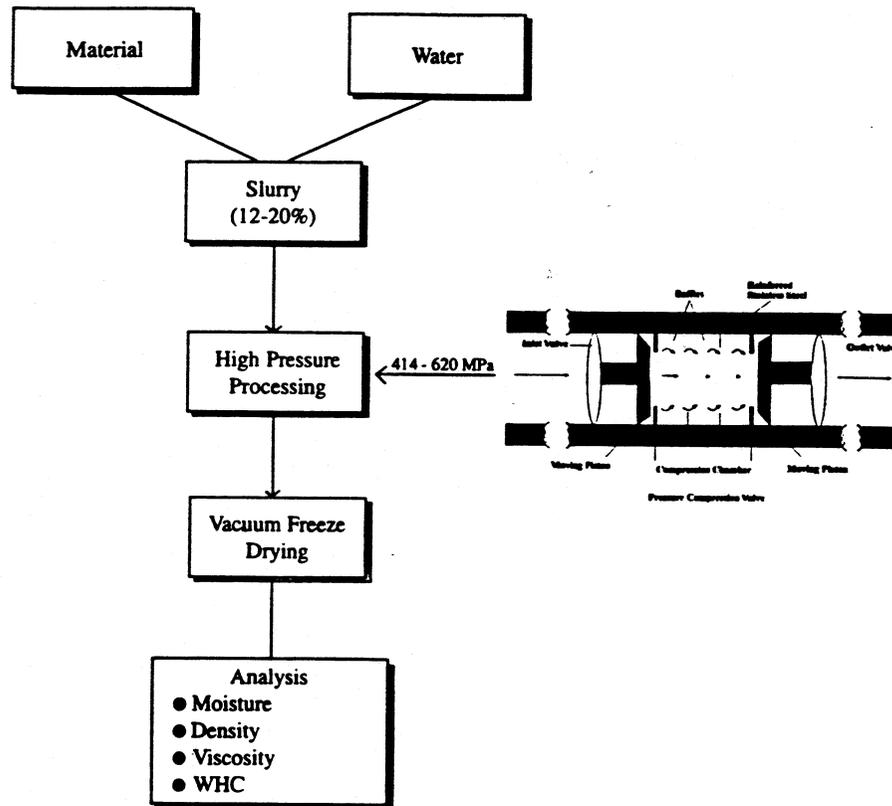


Fig. 1- Flow diagram of the high pressure process, with a schematic illustration of the pressure chamber. WHC = water-holding capacity; NMR = nuclear magnetic resonance.

capacity (WHC) of the fiber and cellulose samples was determined as follows: Samples were ground and sifted through a 210 micron sieve, $10g \pm 0.005g$, placed in a centrifuge tube and 10 mL distilled water were added. After standing for 15 min (with intermittent shaking every 5 min), the samples were centrifuged for 15 min at $1000 \times g$ (Econospin Model, Sorvall Instruments, Wilmington, DE). The supernatant was decanted, and the weightgain in the gel was noted. WHC was calculated as follows:

$$\text{WHC (\%)} = \{(F - G) - C\} / C * 100$$

where F = weight of centrifuge tube and hydrated sample, after decanting (g); G = Tare weight of centrifuge tube (g); and C = weight of dry sample. Viscosities of the starch samples were determined with the Brookfield digital viscometer Model LVTDV-III logged to Rheocalc® software (Brookfield Engineering Laboratories, Inc., Stoughton, MA). The small sample adapter with attached guard legs was used with the ULA spindle. A thermostated water bath was used to control the temperature at 25°C. Statistical analyses for variance (ANOVA) and the Duncan's multiple range test for mean separation were done with a statistical analyses system, SAS for Windows 95®, version 6.12 (SAS Institute, Inc., 1996).

RESULTS

The results of dynamic-pulsed pressure processing under various conditions on starches are presented in Table 1. Analysis of variance in responses from pulsed pressure shows conditions of processing to be significant ($P < 0.05$). Changes in such physical properties as moisture, density, viscosity and shifts in melting point are significantly different ($P < 0.05$). Heating the starches to 70°C (to partially gelatinize the starch) created a condition in which pulsed pressure processing effected significant changes in moisture ($P < 0.01$), density ($P < 0.05$), and shifts in melting peaks ($P < 0.01$), respectively. However, statistically significant changes were not observed with the viscosity. Adjusting the ionic strength to create acidic conditions, did not produce significant changes in response. The results for the starches are presented in Table 2. Moisture varied significantly in modified corn starch, while no significant changes in viscosity were observed for either modified corn starch or native dent starch.

Table 1 - Effect of pulsed-pressure processing on starches (Analysis of Variance)

Process condition	Moisture (%)	Density (g/cm ³)	Viscosity (cp)	DSC* (J/kg)
25°C	NS	NS	NS	2.33*
70°C	2.77**	3.67**	NS	217*
pH	NS	NS	NS	NS

* $P < 0.05$; ** $P < 0.01$; pH: ionic strength was adjusted to pH 5.0 ± 0.2 at room temperature.

*Differential Scanning Calorimeter, peak melt points.

Table 2 - Effect of pulsed-pressure processing on fibers (Analysis of Variance)

Process condition	Moisture (%)	Density (g/cm ³)	WHC (%)	DSC*(J/kg)
25°C	NS	NS	NS	2.33*
70°C	2.52**	2.43**	2.00	NS
pH	NS	5.08	NS	1.44*

* $P < 0.05$; ** $P < 0.01$; pH: ionic strength was adjusted to pH 5.0 ± 0.02 at room temperature.

*Differential Scanning Calorimeter, peak melt points. WHC = water-holding capacity.

The effect of pulsed-pressure processing under different conditions of temperature and acidity on food fibers is presented in Table 3. After processing at 25°C, only shifts in melting peaks were found to be affected significantly ($P < 0.05$). Increasing the fiber temperature to 70°C affected moisture, density and water-holding capacity (WHC) significantly ($P < 0.05$). No significant changes were noted for water properties. The moisture response of food fibers to various high pressure processing conditions is presented in Table 4. Cellulose fiber showed significant increases in moisture with increasing pressure as well as with multiple passes. Reduction in the water-holding capacity in the cellulose fiber after pressure processing is presented in Fig. 2. Significant reduction in WHC was observed under UHP conditions. However, no reduction was observed for wheat bran and also for both fibers at high pressure.

Table 3- Effect of high pressure at different cycles on starches*

Process ^b	Moisture (%)	Viscosity (cp)	Moisture (%)	Viscosity (cp)
0	4.71	1.30	3.70	2.97
1	5.46	1.39	3.95	3.45
2	3.67	1.46	3.97	3.31
3	6.88	1.39	4.43	3.01
4	4.25	1.39	4.52	2.62
PSD	1.1	0.23	0.8	0.98

*70°C

^bProcess: 0=control; 1=one pass at 414 MPa; 2=five passes at 414 MPa; 3=one pass at 620 MPa; 4=five passes at 620 MPa. PSD-Pooled standard deviation.

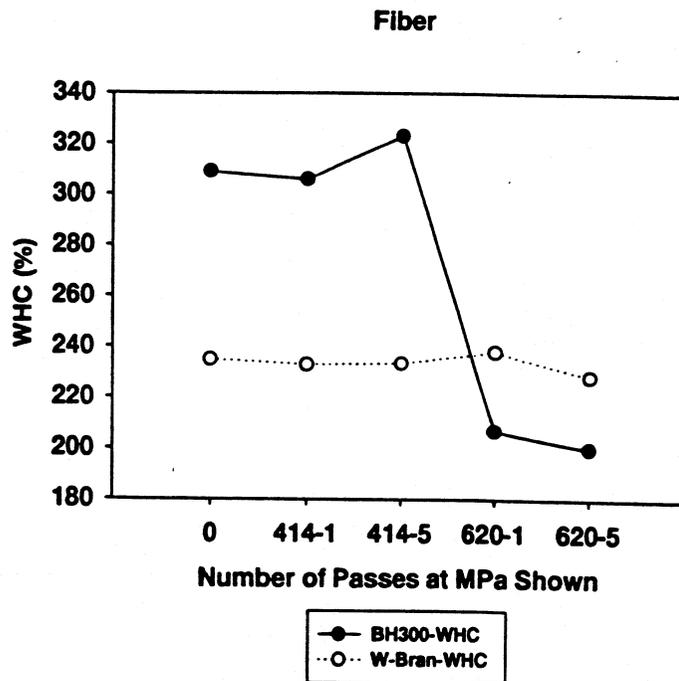


Fig. 2- Water-holding capacity (WHC) of pressure treated fibers. ●—● BH300 = powdered cellulose; ○····○ WBRAN = wheat bran fiber.

Table 4- Effect of high pressure at different cycles on fibers* on moisture content

Process	Cellulose (BH300)	Wheat Bran
0	2.87	5.30
1	3.41	6.57
2	3.47	5.08
3	10.37	5.53
4	10.38	6.73
PSD	1.0	1.01

*70°C

^bProcess: 0=control; 1=one pass at 414 MPa; 2=five passes at 414 MPa; 3=one pass at 620 MPa; 4=five passes at 620 MPa. PSD-Pooled standard deviation.

DISCUSSION

We observed a downward shift in peak melting temperatures with both modified and native corn starch. Stute et al. (1996) showed slight increases in peak melt temperature at 500 MPa for waxy rice starch, and downward shifts in peak melt point for corn starch suspensions. Elevation of temperature improves the effectiveness of pressure treatment. We have observed that elevating temperature to 70°C increases the effect of high pressure processing. High pressure processing does not seem to affect the viscosity of materials with solids content less than 20%. Similar observations have been reported where starches developed very little viscosity at normal paste concentration. To induce gelatinization with UHP, relatively high moisture is needed. It has been shown the pressure induced gelatinization is significantly different from heat induced gelatinization and shows less effective on viscosity (Stute et al., 1996).

The benefit of pressure processing is the ability to impact physicochemical changes without accompanying thermal energy input. However, with dynamic pulsed pressure, we have observed that input of thermal energy is necessary, as time is significantly reduced from 30 to 180 min to 1.0 sec. we have observed density increases from molecular packing, shifts in melt peaks and no changes in viscosity with dynamic pulsed pressure. With cellulose and wheat bran fiber, our results show changes in water-holding capacity and moisture retention with dynamic pressure treated cellulose, but not with wheat bran fiber. The need for a durable mode of batch operations has been suggested. The constraints are the cost of construction and wear of the pulsed pressure vessel as was our experience (Farr, 1990). We have observed that there is significant wear in the pressure chamber leading to loss in effective pressure treatment with time.

CONCLUSION

The effects of dynamic pulsed pressure processing are material temperature and pressure dependent. To affect changes in modified starch, high pressure (414 MPa) was adequate, but not sufficient for native dent starch. Fibers from different sources were affected differently. UHP processing (620 MPa) was needed to reduce the water-holding capacity of cellulose fiber. Wheat bran fiber was not affected by pressures.

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