TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE – 2012, Vol. 12, No. 1, 143–147

Rheological properties of extrusion-cooked starch suspensions

Marcin Mitrus, Agnieszka Wójtowicz, Tomasz Oniszczuk, Leszek Mościcki

Department of Food Process Engineering, Faculty of Production Engineering,
University of Life Sciences, Doświadczalna 44, 20-280 Lublin, Poland,
marcin.mitrus@up.lublin.pl

Summary. The influence of extrusion-cooking process parameters on the apparent viscosity of the extrusion-cooked starch suspensions was investigated. Baro-thermal treatment parameters showed changes in apparent viscosity of the obtained suspensions. The moisture content of the raw material and process temperature had the most strongly influence, much lesser impact was exerted by the extruder's screw speed. Apparent viscosity of extrusion-cooked starch suspensions varied within the range: (338-2504) mPa×s for potato starch, (481-3347) mPa×s for corn starch and (1419-3441) mPa×s for wheat starch.

Key words: starch, extrusion cooking, apparent viscosity, rheology.

INTRODUCTION

Native starch has different industrial applications, however, due to many disadvantages (e.g. insolubility in cold water), it's limited. Disadvantages of native starch can be reduced or even eliminated, through its modification by various methods. The simplest method of physical modification of starch is thermal or pressure-thermal treatment. As a result of heating the grain structure is destroyed and there is a partial starch gelatinization. During this process hydrogen bonds, that stabilize the tertiary and quaternary conformational structure of macromolecules, are disrupted [20]. Various forms of drying, extrusion or high pressure treatment are used for this purpose [2, 6, 21, 22].

Extrusion-cooking technique, widely used in food processing, comes from a well-known in the plastics extrusion techniques for thermoplastic materials. In general terms, extrusion-cooking of the raw material of plant origin is the extrusion of bulk material under high pressure and high temperature. This causes the significant changes in physical and chemical quality of the processed material. During pressure-thermal treatment, material is mixed, compacted, compressed, liquefied and plasticity in the end zone of the extruder. Extrusion pressure can reach up to 20 MPa and temperature of the slurry to 200°C. The scope of physical and chemical changes in processed raw materials depends mainly on the assumed parameters of the extrusion-cooking process and the construction of the extruder. Currently, various types of food fancy goods such as crisps, snacks, meat analogs, as well as pet food and aquafeed or thermoplastic starch are produced using that technique [12, 14, 15, 17].

Extrusion-cooking technique allows for the obtainment of pressure-thermally modified starches with different physical and chemical properties. Properties of the obtained modified starches can be created (within certain limits) depending on the process parameters used. The extrusion-cooker can be treated as a bioreactor. Such pressure-thermal process allows for the obtainment of modified starches with a wide range of degree of gelatinization, with different water absorption and solubility and the different rheological properties of starch pastes. These products may find wide application in food industry as food additives, very often by replacing chemically modified starchy products. Extrusion-cooked starch may find its use as a component of food products in the manufacture of instant products, different kinds of fillings in the confectionery industry, as a gelling agent, structure stabilizer and water- or fat-absorbent fillers. That may be very attractive from the consumer point of view. Application extrusion-cooking is a relatively cheap alternative in the production of modified starches.

Physical and chemical modifications of starch have an influence on the changes of rheological properties of starch suspensions. There are many methods of testing the food rheological properties [3, 7]. Apparent viscosity of the starch suspensions and pastes can be studied during the process of gelatinization [1, 5, 8, 18]. Most often viscosity of suspensions of native and modified starch is tested after heating process in order to gelatinization of starch [4, 13, 16, 19].

The objective of this research was to determine the effect of extrusion-cooking process parameters on the apparent viscosity of extruded starch suspensions prepared in room temperature.

MATERIALS AND METHODS

The basic raw material for investigations was: the commercial corn starch Meritena 100 type produced by T&L (Slovakia), wheat starch Meritena 200 type produced by SYRAL BELGIUM N.V. (Belgium) and potato starch Superior type produced by "PEPEES" S.A. in Lomza (Poland). During the extrusion-cooking process the 4 levels of moisture content of raw material (17, 20, 25 and 30%) were used. In order to obtain expected moisture content, starch was mixed with sufficient amount of water and stored for 24h in air tight polyethylene bags at room temperature to make whole sample material homogeneous.

Extrusion-cooking of potato starch was carried out using a modified single screw extrusion-cooker TS-45 (Polish design) with L/D = 16. The die with one opening with a diameter of 3 mm was used. During the study three temperature of extrusion process (100, 120 and 140°C) and a variable speed screw (60, 80, 100, 120 rpm) were used.

The suspensions (10% w/w dry mass basis) of grounded extrudates with distilled water were prepared by continuous stirring for 10 minutes, than apparent viscosity was measured using a Zwick testing machine BDO-FB 0,5 TH type, equipped with a back extrusion chamber 60 mm height and internal diameter of 50mm. A piston of 46 mm diameter and 20 mm height was used during measurements. The measurement cycle was 60 mm, test speed 100 mm/min, a slit width - 2 mm. The data was subjected to analysis of variance (ANOVA) by Duncan's test (α = 0.05) using SAS 9.1 software

RESULTS

All native starches formed a unstable suspensions. Viscosity measurements of these suspensions were difficult because of starch sedimentation. Apparent viscosity of aqueous suspensions of native starches was about 3 mPas.

Extruded cereals starches formed opaque suspensions, while potato starch extrudates formed a transparent and translucent suspension. The suspensions obtained from starch contained 30% of moisture characterized ability to stratification. This was probably due to insufficient degree of fragmentation of the extrudates (Fig. 1).

Extruded wheat starch formed aqueous suspensions with a high apparent viscosity in the range from 1419 to 3441 mPas after 10 minutes of mixing. Extruded corn starch formed aqueous suspensions with a moderately high apparent viscosity in the range from 481 to 3347 mPas after 10 minutes of mixing. Extruded potato starch

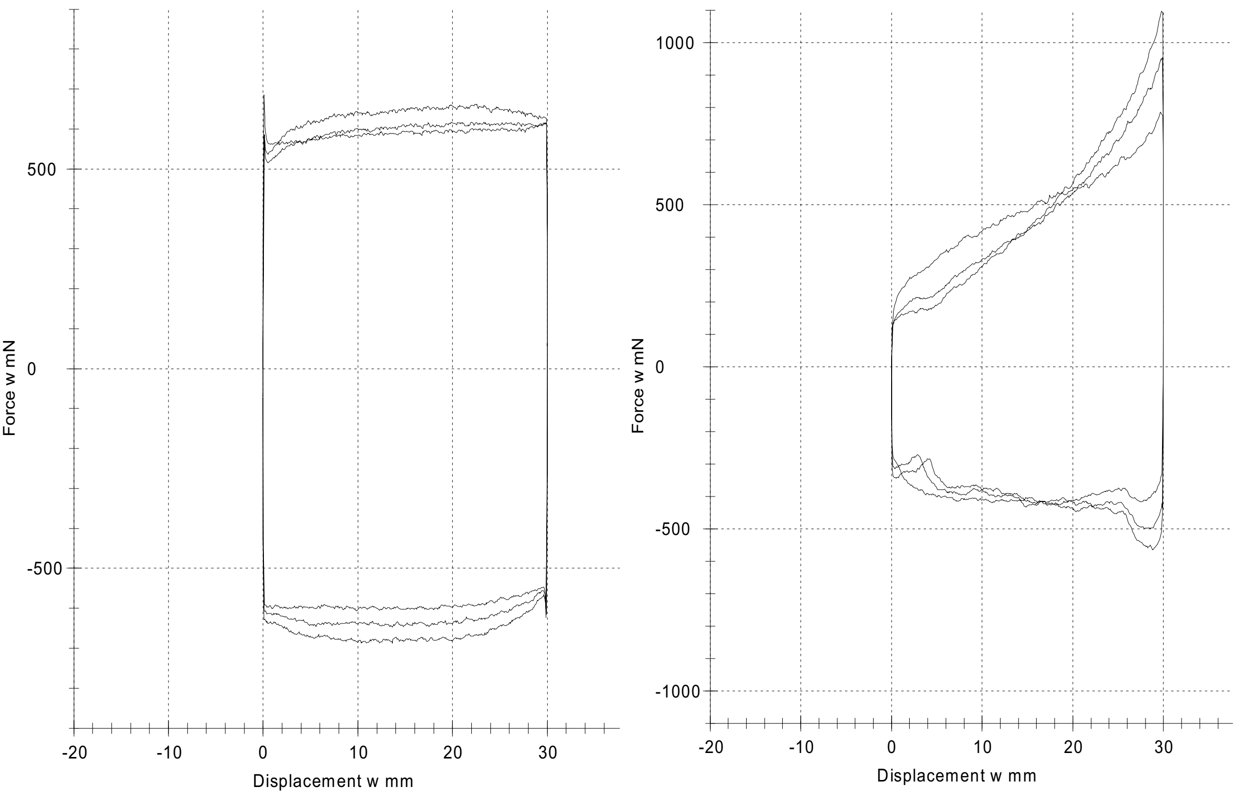

Fig. 1. Example of test results for corn starch extruded at 100°C with screw speed of 60 rpm; moisture content 17 and 30%, respectively

formed aqueous suspensions with a relatively low apparent viscosity in the range (338-2504) mPas after 10 minutes of mixing. Statistical analysis revealed significant effects of the raw material moisture content and screw speed on the apparent viscosity of extruded starch suspensions (tab.1).

Table 1. The results of measurements of the apparent viscosity of aqueous suspensions of wheat starch extruded at 140°C (the same letter in the row means no significant differences, the level of significance α = 0,05)

Moisture content before extrusion [%]	Apparent viscosity [mPa×s]			
	60 [rpm]	80 [rpm]	100 [rpm]	120 [rpm]
17	3384^{a}	3343^{a}	3441^{a}	3068^{b}
20	2799^{b}	3563^{a}	3410^{a}	3657^{a}
25	2026^{c}	3029^{a}	2417^{b}	2734^{ab}
30	2484^{b}	3079^{a}	2537^{b}	2100^{c}
Screw speed [rpm]	**17%**	**20%**	**25%**	**30%**
60	3384^{a}	2799^{b}	2026^{c}	2484^{b}
80	3343^{a}	3563^{ab}	3029^{c}	3079^{bc}
100	3441^{a}	3410^{a}	2417^{b}	2537^{b}
120	3068^{b}	3657^{a}	2734^{c}	2100^{d}

The suspensions obtained from wheat starch extruded at higher screw speeds had a higher viscosity. The extrudates of wheat starch with higher moisture content formed suspensions with lower viscosity. The viscosity of the suspensions obtained from extruded wheat starch increased with increase of the extrusion temperature.

In a case of suspensions obtained from extruded corn starch it was found that an increase in moisture content of the processed material causes an increase in suspensions viscosity (fig. 2). The statistical analysis revealed insignificant effect of the extrusion-cooker screw speed on the apparent viscosity of extruded corn starch suspensions.

Potato starch extrudates produced at the higher screw speed formed the suspensions with lower viscosity. Increase in moisture content of the processed potato starch had a positive effect on the viscosity of the formed suspensions.

The extrusion-cooking process has great impact on physical and chemical properties of the processed starch, especially on its water absorption (WAI) and the solubility in cold water (WSI) [9, 10, 11]. Researches revealed that changes in WAI and WSI influenced on the apparent viscosity of the extruded starch suspensions (fig. 3).

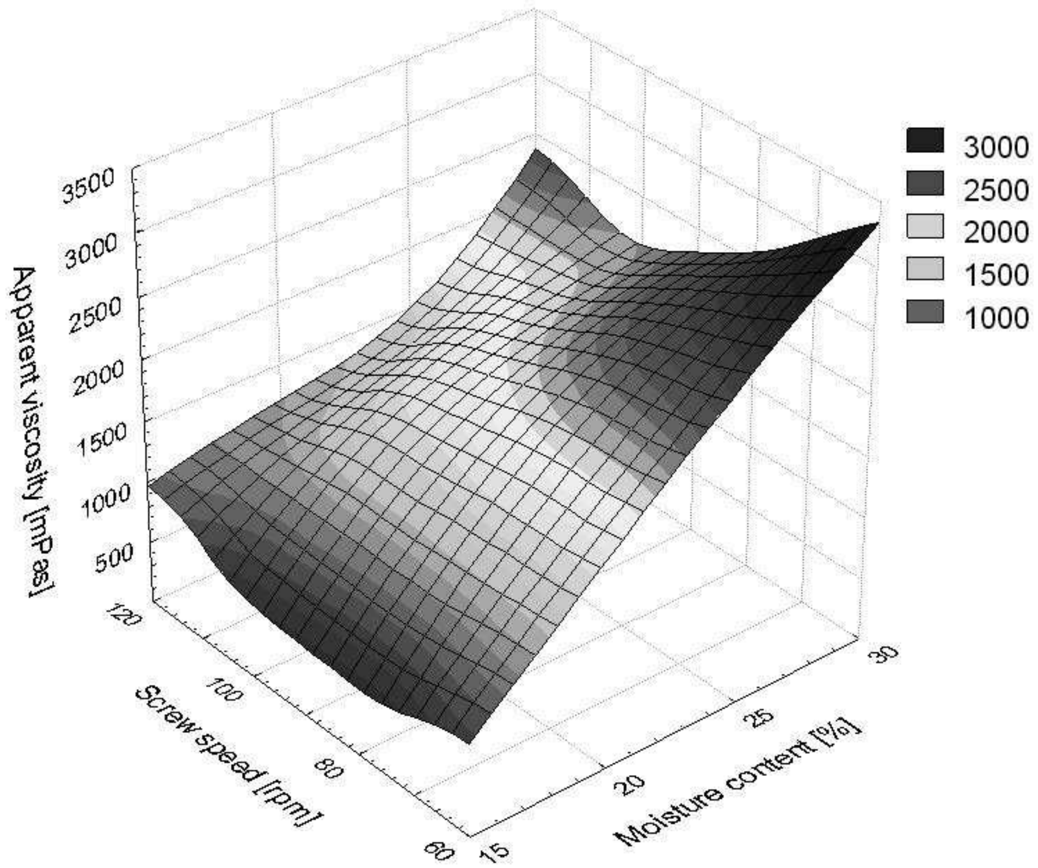

Fig. 2. Influence of the process parameters on the apparent viscosity of the corn starch-water suspensions for starch extruded at 120°C

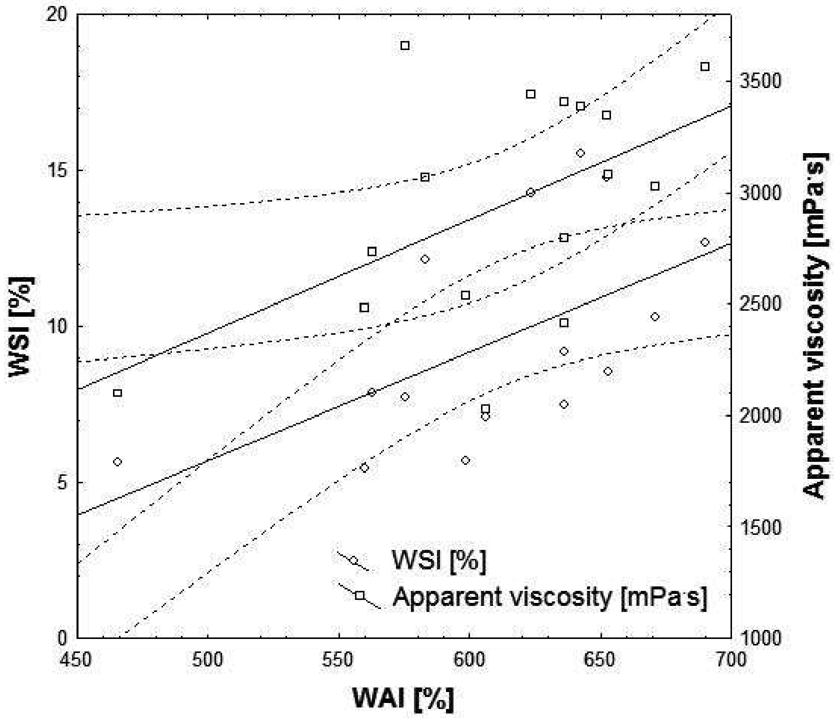

Fig. 3. Influence of WAI and WSI on the apparent viscosity of the extruded wheat starch suspensions

During the measurements was found that increase in starch water absorption involves an increase of viscosity of starch suspensions. This effect was observed for all types of the extruded samples. Increase of starch solubility in a cold water decreased viscosity of starch suspensions. Only for wheat starch increase of the suspensions viscosity with WSI increase was observed.

CONCLUSIONS

Extrusion-cooking process parameters determined the apparent viscosity of the extruded starch suspensions. The strongest effect was observed with the moisture content of starch before extrusion-cooking; the process temperature and the extruder screw speed were less affected. Probably this is due to the course of the starch gelatinization and degradation process and, in consequence, with the WAI changes and the solubility in cold water.

Extruded wheat starch formed aqueous suspensions with a high apparent viscosity in the range (1419-3441) mPas after 10 minutes of mixing. Extruded corn starch formed aqueous suspensions with a moderately high apparent viscosity in the range (481-3347) mPas after 10 minutes of mixing. Extruded potato starch formed aqueous suspensions with a relatively low apparent viscosity in the range of (338-2504) mPas, after 10 minutes of mixing.

REFERENCES

1. **Bhattacharya S., Sudha M.L., Rahim A. 1999.** Pasting characteristics of an extruded blend of potato and wheat flours, Journal of Food Engineering, 40, p. 107-111.
2. **Błaszczak W., Valverde S., Fornal J. 2005.** Effect of high pressure on the structure of potato starch, Carbohydrate Polymers, 59, p. 377-383.
3. **Bourne M.C. 2002.** Food Texture and Viscosity. Concept and Measurement, Elsevier Inc.
4. **Desse M., Ang S., Morris G.A., Abu-Hardan M., Wolf B., Hill S.E., Harding S.E., Budtova T., Mitchell J.R. 2009.** Analysis of the continuous phase of the modified waxy maize starch suspension, Carbohydrate Polymers, 77, p. 320-325.
5. **Han J-A., Be Miller J.N. 2007.** Preparation and physical characteristics of slowly digesting modified food starches. Carbohydrate Polymers, 67, p. 366-374.
6. **Kawai K., Fukami K., Yamamoto K. 2007.** Effects of treatment pressure, holding time, and starch content on gelatinization and retrogradation properties of potato starch-water mixtures treated with high hydrostatic pressure, Carbohydrate Polymers, 69, p. 590-596.
7. **Kobus Z., Kusińska E. 2010.** Effect of temperature and concentration on rheological properties of tomato juice, TEKA Commission of Motorization and Power Industry in Agriculture, Vol. X, p. 170-178.
8. **Loisel C., Maache-Rezzoug Z., Esneault C., Doublier J.L. 2006.** Effect of hydrothermal treatment on the physical and rheological properties of maize starch, Journal of Food Engineering, 73, p. 45-54.
9. **Mitrus M., Wójtowicz A. Mościcki L. 2010.** Modyfikacja skrobi ziemniaczanej metodą ekstruzji, Acta Agrophysica, 16(1), p. 101-109.
10. **Mitrus M., Oniszczuk T., Mościcki L. 2011.** Changes of specyfic mechanical energy during extrusion-cooking of potato starch, TEKA Commission of Motorization and Power Industry in Agriculture, Vol. XIc, p. 200-207.
11. **Mitrus M., Wójtowicz A. 2011.** Extrusion-cooking of wheat starch, TEKA Commission of Motorization and Power Industry in Agriculture, Vol. XIc, p. 208-215.

12. **Moscicki L. 2011.** Extrusion-Cooking Techniques. Applications, Theory and Sustainability, Wiley-VCH Verlag GmbH&Co. KGaA, Weinheim.
13. **Nuessli J., Handschin S., Conde-Petit B., Escher F. 2000.** Rheology and structure of amylopectin potato starch dispersions without and with emulsifier addition, Starch, 52, p. 22-27.
14. **Rejak A., Mościcki L. 2011.** Selected mechanical properties of TPS films stored in the soil environment, TEKA Commission of Motorization and Power Industry in Agriculture, Vol. XIc, p. 264-272.
15. **Singh S., Gamlath S., Wakeling L. 2007.** Nutritional aspects of food extrusion: a review, International Journal of Food Science & Technology, 42, p. 916-929.
16. **Singh N., Isono N., Srichuwong S., Noda T., Nishinari K. 2008.** Structural, thermal and viscoelastic properties of potato starches, Food Hydrocolloids, 22, p. 979-988.
17. **Sobczak P. 2006.** Sorbitol addition on extrusion process, TEKA Commission of Motorization and Power Industry in Agriculture, Vol. VIa, p. 163-169.
18. **Srichuwong S., Sunarti T.C., Mishima T., Isono N., Hisamatsu M. 2005.** Starches from different botanical sources II: Contribution of starch structure to swelling and pasting properties, Carbohydrate Polymers, 62, p. 25-34.
19. **Tako M., Hizukuri S. 2003.** Rheological properties of wheat (halberd) amylopectin, Starch, 55, 345-349.
20. **Van den Einde R., Bolsius A., Van Soest J., Janssen L.P.B.M., Van der Goot A., Boom R. 2003.** The effect of thermomechanical treatment on starch breakdown and the consequences for the process design, Carbohydrate Polymers, 55, p. 57-63.
21. **Wójtowicz A. 2011.** Influence of extrusion-cooking parameters on selected physical and textural properties of precooked maize pasta products, TEKA Commission of Motorization and Power Industry in Agriculture, Vol. XI, p. 441-449.
22. **Yan H., Zhengbiao G.U. 2010.** Morphology of modified starches prepared by different methods, Food Research International, 43, p. 767-772.

WŁAŚCIWOŚCI REOLOGICZNE ZAWIESIN SKROBI EKSTRUDOWANYCH

S t r e s z c z e n i e . W trakcie badań określano wpływ parametrów procesu ekstruzji na zmiany lepkości pozornej zawiesin skrobi ekstrudowanych. Parametry obróbki ciśnieniowo-termicznej miały duży wpływ na zmiany lepkości pozornej zawiesin ekstrudowanych skrobi. Najmocniej na lepkość oddziaływała wilgotność surowca i temperatura procesu, prędkość ślimaka ekstrudera miała mniejszy wpływ. Lepkość pozorna zawiesin ekstrudowanej skrobi zmieniała się w granicach: (338-2504) mPa×s dla skrobi ziemniaczanej, (481-3347) mPa×s dla skrobi kukurydzianej i (1419-3441) mPa×s dla skrobi pszennej.

S ł o w a k l u c z o w e : skrobia, ekstruzja, lepkość pozorna, reologia.