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CHANGES OF SPECIFIC MECHANICAL ENERGY DURING EXTRUSION COOKING OF THERMOPLASTIC STARCH

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Summary. Changes of specific mechanical energy during extrusion cooking of thermoplastic starch are presented in the paper. The results showed that thermoplastic starch extrusion cooking is related with rather low energy. The final aim of the investigations is to produce commercial disposable products from pure starch and eliminate traditional synthetics.

Key words: thermoplastic starch, extrusion cooking, specific mechanical energy

INTRODUCTION

Management of solid packaging waste causes an increasing concern all over the world. Some of the most vital problems are growing environmental pollution, the reduced space for landfill and plastic wastes.

The solution should be the development of safer and more effective recycling technologies as well as generation of new materials, mainly biodegradable, easy to be reused or recycled.

Taking into account some drawbacks of the current technologies for biodegradable material manufacture researches on a large scale have been performed to obtain the highest possible starch share in starch-plastics composites. The final aim of the investigations is to produce commercial disposable products from pure starch and eliminate traditional synthetics The so called thermoplastic starch (TPS) seems to be a perfect solution as it can be processed with conventional technologies for synthetic plastics manufacture (extrusion cooking, pressing high pressure, injection moulding). Having been used up, these products can be utilised in a simple way, e.g. in a composting process.

MATERIALS AND METHODS

Materials

The basic material for investigations was obtained from potato starch Superior type produced by the Food Industry Plant „PEPEES" S.A. in Lomza (Poland), Potato Industry Plant in Braniewo (Poland) and AVEBE b.a. from the Netherlands.

The comparative studies were made on the wheat starch Excelsior MB type manufactured by AVEBE b.a. in Holland and corn starch Cargill 2000 type produced by Hanseland B.V. in the Netherlands. The trials to produce biodegradable extrudates from wheat and maize starch were performed in the above-described extruder in the blends identical as for potato starch.

Among the numerous aid materials mentioned in the professional literature applied as plasticizers or additions improving the quality of the obtained materials, the most popular proved to be glycerol of 99% purity and it was used in the tests, being added in the amount of 15-30% of starch dry mass. The impact of plasticizer addition on extrusion cooking parameters and the physical properties of the produced TPS were examined.

Blend preparation

All the starch types were blended into 20 kg of sample material, while mixing and damping the above-mentioned aid materials were added.

As a result of the repeated trials there the effective agitation time in a bakery kneading pan was determined, i.e. 20 min, that assured loose and friable blend structure.

The obtained mixture was stored for 24 h in air tight polyethylene bags at room temperature to make the whole sample material homogeneous, to facilitate penetration of additions into starch granules and protect it from moisture absorption.

The prepared mixtures were delivered to the feeding device of the modified extruder to undergo baro-thermal treatment.

Extrusion cooking

A modified version of a single screw extruder TS-45 (Polish design) was used fitted with a new plastifying system of L/D = 16/1 as well as additional cooling system of the final cylinder part (Photo 1) [Wójtowicz 2003]. It aimed at an improvement of material processing, lowering product temperature and consequently, a decrease of expansion level as well as elimination of steam bubbles formation with the maintenance of the required thermal conditions for TPS production. The extruder head was also modified as it was fitted out with brass die with 3 openings of 1.5 mm diameter and 20 mm depth. The extruder was equipped with a high-speed cutter for chopping a product into a granulation of fixed, small dimensions. To avoid the granules sticking together was an additional cooling was installed of the extrudate discharged from the crosshead by a nozzle with compressed air assembled at the crosshead top.

Power consumption

Power consumption measurement was performed with a standard wattmeter connected to the extruder drive unit. With regard to the parameters of a Shrage type engine installed in the extruder TS-45, engine working load and performance were recorded at each capacity test, and the obtained results were converted to an index of specific mechanical energy consumption (SME) after the formula given by Levin [Levine 1997, Janssen et al. 2002]:

$$SME = \frac{n \cdot P \cdot O}{n_m \cdot Q} \quad kWhkg^{-1} \tag{1}$$

where: n – screw rotations, min^{-1},
n_m – maximal screw rotations min^{-1},
P – power, kW,
O – engine loading, %,
Q – extruder capacity, kgh^{-1}.

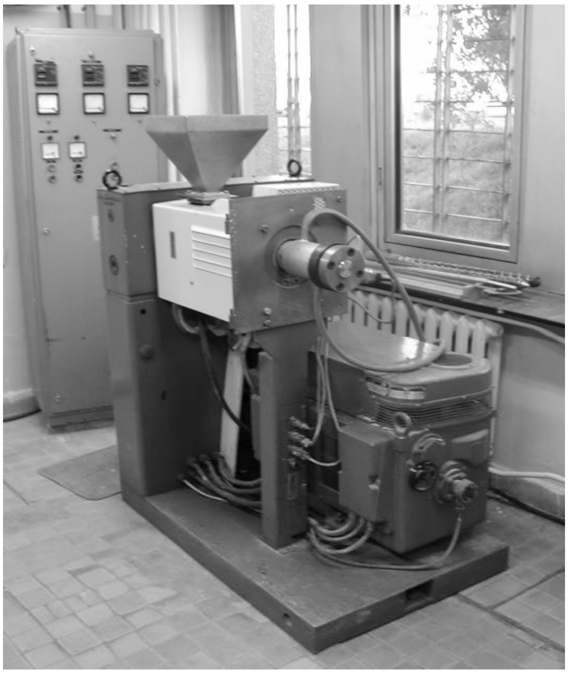

Fig. 1. The modified single screw extruder TS-45

RESULTS

Application of extrusion cooking technique for plant starch processing into TPS requires a very significant factor, that is the determination of specific mechanical energy (SME) necessary to obtain the product mass unit. According to Bindzus *et al*. [2002], when wheat, maize and rice starch were processed at a twin screw extruder the SME values changed in the range 0.081–0.365 kWhkg^{-1}. Brümmer and others [2002] report that at the maize starch extrusion on a twin screw extruder the SME reached values running from 0.1 to 0.25 kWhkg^{-1} and this parameter value is only very slightly related with material moisture. The researches on the potato starch extrusion carried out on a twin screw extruder by Della Valle *et al.* [1995] indicated that specific mechanical energy changed within the interval 0,1 to 0,32 kWhkg^{-1}. Wiedmann and Strobel [1991] in their investigations on the extrusion of wheat TPS recorded the SME ranging from 0.1 to 0.55 kWhkg^{-1} , depending on material moisture.

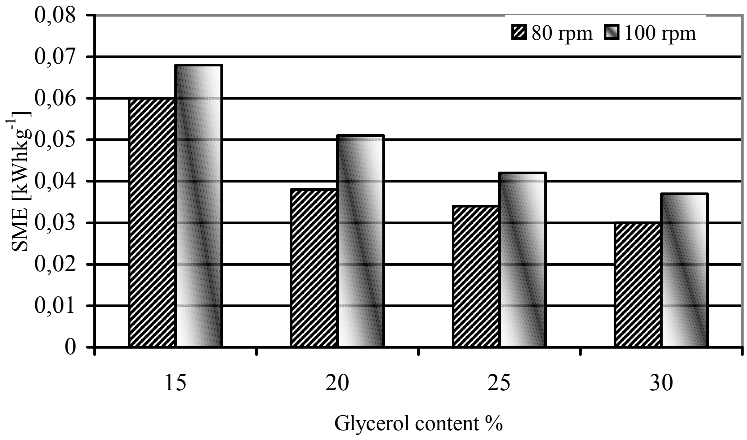

Fig. 1. The SME changes at potato TPS extrusion in relation to glycerol percentage in mixture.

The present author's studies showed that material composition and extruder screw rotation speed exerted a substantial impact on SME during TPS processing. The growth of glycerol content in material mixture induced the SME decrease (Fig. 1). Moreover, an increased extruder screw rotation speed causes a mechanical energy rise. The SME values reached 0.068 kWhkg^{-1} for the mixtures with 15% of glycerol content processed at 100 rpm rate, while at 80 rpm for the same mixture the obtained values were 0.06 kWhkg^{-1}. The lowest SME values were recorded for the mixtures with 30% glycerol content [Mitrus 2004].

Mollymäki *et al.* [1997] proved a significant influence of glycerol content and material moisture on specific mechanical energy at barley starch extrusion. They observed SME changes running from 0.087 to 0.24 kWhkg^{-1}. With material moisture and glycerol percentage growth the SME value decreases, however in the starch plastified only with glycerol the SME values are higher compared to the starch plastified exclusively with water. At extrusion performed with single screw extruder when the potato, wheat and maize starch were plastified only with water the following SME values were obtained: 0.072, 0.079, 0.094 kWhkg^{-1}, respectively.

The investigations proved that the changes of SME at TPS production are affected by material blend moisture. The higher material moisture, the higher SME values are. The highest SME values recorded (0.076 kWhkg^{-1}) referred to potato starch of 20% moisture with 20% of glycerol content.

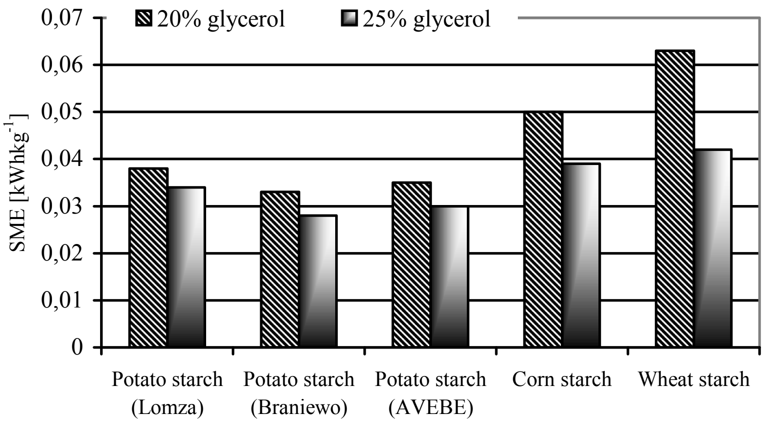

Fig. 2. Specific mechanical energy of extruder for mixtures with differing starch type contents

All of the investigated starch types were found to show lower SME values at glycerol content growth in mixture (Fig. 2). The lowest SME values were obtained at potato starch extrusion, whereas the highest at wheat starch processing. It was also detected that there are differences in SME values for potato starch with varied amylose content. The highest SME values were shown for potato starch with 24% amylose, the lowest for starch with 22,1% amylose content [Mitrus 2004].

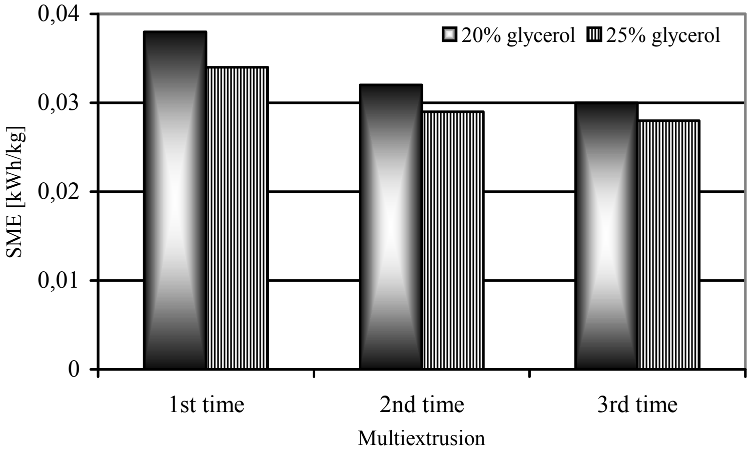

Fig. 3. The SME changes in relation to potato TPS extrusion repetition

During the multiple potato TPS extrusion it was found out that SME changes with extrusion repetition (Fig. 3). The higher number of extrusion repetition for the same material, the lower SME is recorded [Mitrus 2004]. These results can indicate a degree of crystallographic structure destruction of the processed starch. Unprocessed, half-crystallite starch needs higher energetic input to get melted and processed than thermoplastic starch of amorphous structure, nearly deprived of any crystallographic structures at all. As Igura's studies show [Iguara *et al*. 2001], with extrusion repetition increase, there appears a drop in shearing stresses occurring at material processing that persist at the constant level after quintuple extrusion.

CONCLUSIONS

Thermoplastic starch extrusion cooking is related with rather low energy input, i.e. 0.07 $kWhkg^{-1}$ at average. Extruder power demand at the baro-thermal treatment depended on material composition of the processed mixtures: an increase in glycerol content in mixture induced process energy consumption decrease.

The SME value depends on the type of starch used in production. The lowest SME values were obtained at potato starch extrusion, whereas the highest at wheat starch processing. It was also detected that there are differences in SME values for potato starch with varied amylose content.

Specific mechanical energy changes with extrusion repetition. The higher number of extrusion repetition for the same material, the lower SME was recorded.

REFERENCES

Bindzus W., Livings S.J., Gloria–Hernandez H., Fayard G., van Lengerich B., Meuser F. 2002: Glass transition of extrudet wheat, corn and rice starch. Starch, 54, 393.

Brümmer T., Meuser F., Van Lengerich B., Niemann C. 2002: Effect of extrusion cooking on molecular parameters of corn starch. Starch, 54, 1.

Della Valle G., Boché Y., Colonna P., Vergnes B. 1995: The extrusion behaviour of potato starch. Carbohydrate Polymers, 28, 255.

Iguara N., Katoh T., Hayakawa I., Fujio Y. 2001: Degradation profiles of potato starch melts through a capillary tube viscometer. Starch, 53, 623.

Janssen L.P.B.M., Mościcki L., Mitrus M. 2002: Energy aspects in food extrusion. International Agrophysics, 16, 191.

Levine L. 1997: More on extruder balance. Cereal Foods World, 42, 22.

Mitrus M. 2004: Wpływ obróbki barotermicznej na zmiany właściwości fizycznych biodegradowalnych biopolimerów skrobiowych. Rozprawa doktorska, Lublin.

Myllymäki O., Eerikäinen T., Suortti T., Forssell P., Linko P., Poutanen K. 1997: Depolymerization of barley starch during extrusion in water glycerol mixtures. Lebensmiittel Wissenhaft und Technologie, 30, 351.

Wiedmann W., Strobel E. 1991: Compounding of thermoplastic starch with twin-screw extruders. Starch, 43, 138.

Wójtowicz A. 2003: Badania procesu ekstruzji makaronów błyskawicznych, Rozprawa doktorska, Lublin.