Selected aspects of thermoplastic starch production

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Summary. This paper presents results of process efficiency and specific mechanical energy consumption (SME) during the extrusion-cooking of thermoplastic starch (TPS). The tests proved that the process efficiency of TPS extrusion-cooking largely depends on the amount of plasticizer. With the increase of plasticizer in the mixture reduction in process efficiency was observed. Higher moistening of raw materials resulted in increased TPS efficiency. SME values ranged from 0.060 to 0.076 kWh·kg^{-1} and were dependent on the extruder-cooker screw speed, the mixture recipe and multiplicity of extrusion repetitions for thermoplastic starch processing.

Key words: thermoplastic starch, extrusion-cooking, process efficiency, SME.

INTRODUCTION

Potatoes, corn, rice, tapioca, wheat, rye are only some of plants which are widely used to extract the starch. Starch can be added in varying amounts to plastics to get more environmentally friendly materials [5, 22, 23]. Due to the amount of starch in the mixture for the production of biodegradable plastic materials there should be mentioned plastic-modified starch (from 5 to 15% starch) and plastics based on starch with (40-60) % starch content.

Scientists constantly aim at complete replacement of plastics by natural materials. Thermoplastic starch (TPS) can be one of those materials [3, 9, 12]. In biopolymers starch added to the mixture occurs in two forms: native and extruded form. Extruded starch is different than the native starch as to rheological and physical properties, including the structure. Extruded starch also has a much higher solubility in water [2, 18].

TPS can be obtained by destroying the crystalline nature of starch granules by thermal and mechanical processing [1, 8]. The process needs addition of plasticizers (e.g. water), because the melting point of pure dry starch is much higher than its temperature of decomposition. Shear forces and temperature cause a break of natural crystalline structure of starch granules. The continuous polymer phase is creating.

During the extrusion-cooking process other plasticizers, like glycerin, propylene glycol, glucose or sorbitol, can be used to increase flexibility and improve material properties, but glycerol is most commonly used. Addition of sorbitol induces water and oxygen vaporization through the produced TPS film. Fat added to starch reduces the water vapor permeability. Various functional additives, such as emulsifiers, vegetable fibers, bark or cellulose are also used during the manufacturing process to change mechanical properties of rigid forms of TPS packaging.

Thermoplastic starch can be used as a standalone packaging material or as a component which improves degradation of plastics. Application of TPS is possible due to the relatively short time of degradation to CO_2 and water. Biocomposites which are enriched with starch are used for films, containers, and in the production of foams used in packaging sector [11, 13].

MATERIALS AND METHODS

In the experiments potato and cereal starches were used, additives were: glycerol and water. Moisture of prepared mixtures was from 15 to 28% using the method described by Szymanek and Sobczak [17]. Glycerol content was from 15 to 30% of dry starch mass. The extrusion-cooking process was carried out with a modified single screw extrusion-cooker type TS-45 (Polish design) equipped with elongated plastic-forming section and additional barrel-cooling section before the die [10, 20, 21]. Technical parameters of the equipment were as follow: L/D=16/1, screw rotation speed regulation from 50 to 130 rpm, forming die with 3 openings 1.5 mm each.

Prepared mixtures were processed at the temperature ranged from 80 to 100°C with screw speed 80 and 100 rpm. The process efficiency was measured by products collection after 10 minutes of regular production for each sample at different conditions. The measurements were registered six-times.

Power consumption was measured using standard register connected to extruder's motor for each recipe and screw speed used [16, 19]. After the consideration of motor load and process efficiency, the SME (specific mechanical energy) values were calculated according to the method described by Ryu and Ng [15]:

$$SME = \frac{rpm[test]}{rpm[rated]} \times \frac{\%\ motor\ load}{100} \times \frac{motor\ power[rated]}{feed\ rate} \left[\frac{kWh}{kg} \right]$$

RESULTS

Efficiency of TPS processed by extrusion-cooking depended on glycerol content in prepared mixtures [6]. Process efficiency decreased with increasing glycerol content in the mixture. Increase of glycerol content in the prepared mixture caused almost twice lower efficiency at extreme contents of glycerol at 80 rpm screw speed. With higher screw speed process efficiency increased. It has been observed that during processing highest glycerol content the efficiency of the samples with extrusion-cooking at 100 rpm screw speed was almost 50% smaller.

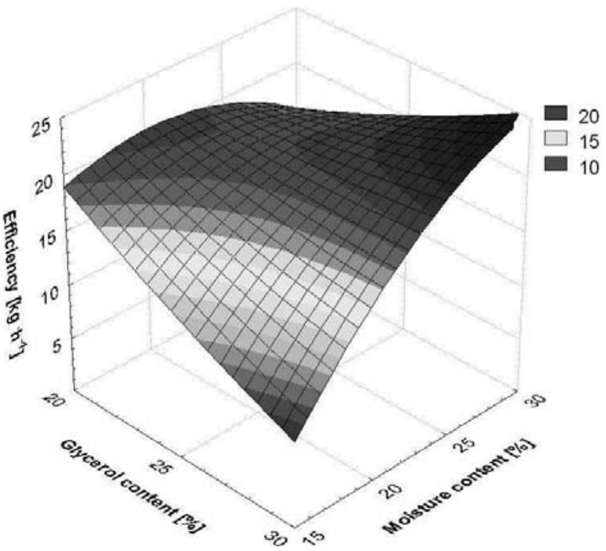

Fig. 1. Efficiency of potato TPS extrusion-cooking depend on glycerol content and mixture moisture

Mitrus [6] has found that also an important role is played by moisture content of processed material. Analyses have shown that extrusion-cooking efficiency increased with higher moisture of potato starch prepared mixture (Fig. 1). If higher glycerol content in the mixture was used, the increase in efficiency was more intense. TPS extrusion efficiency was almost the same for samples with moisture content of 25%. With increase of moisture content of raw materials over 20% the efficiency has been reduced. There was only one exception – a mixture with 30% content of glycerol. In this case TPS extrusion-cooking efficiency was increased with higher moisture.

Using different types of starches, differences in TPS efficiency were observed (Fig. 2). For all the tested starches, it was observed that the higher content of glycerol in prepared mixtures reduced process efficiency [6]. The highest efficiency was recorded using potato starch. The smallest values, twice as low as for potato, were reported in the case of wheat starch.

Efficiency of TPS extrusion-cooking process depends on the number of extrusion repetitions for the same material (Fig. 3). It was observed that the efficiency of the extrusion-cooking of thermoplastic potato starch decreased at multiple extrusions, regardless of glycerol content in the prepared mixture [6].

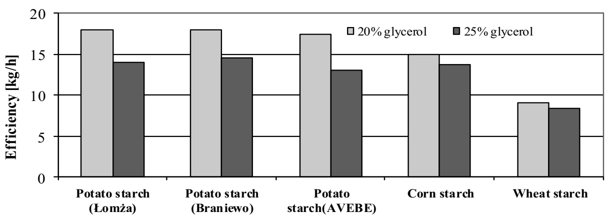

Fig. 2. Effect of starch type and glycerol content on efficiency of TPS extrusion-cooking

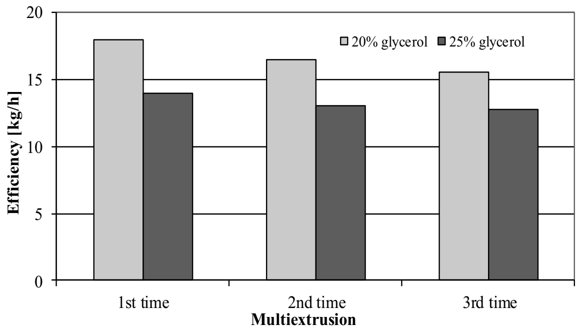

Fig. 3. Efficiency of potato TPS extrusion-cooking dependent on the number of extrusion repetitions

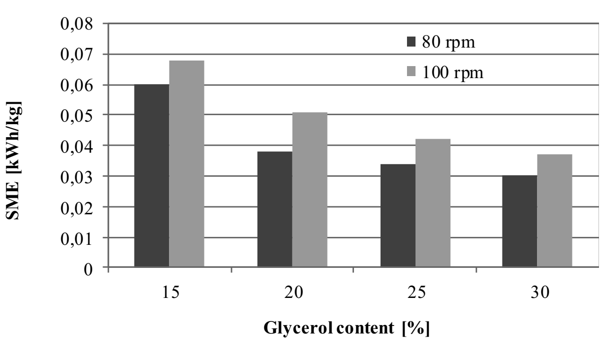

Fig. 4. The SME changes during the extrusion-cooking of thermoplastic potato starch in relation to glycerol content in mixture

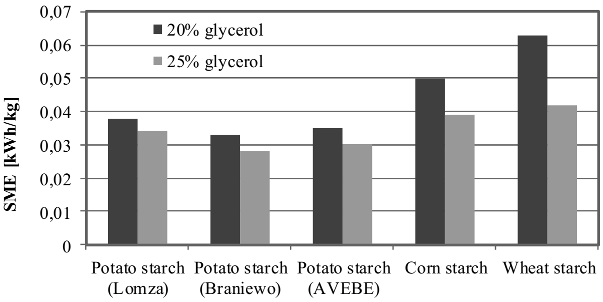

Fig. 5. Effect of starch type and glycerol content on SME

In industrial starch processing with application of extrusion-cooking technology determination of specific mechanical energy consumption (SME) is an important parameter to obtain the product unit costs [4].

It was observed that changes in SME during TPS production are mostly dependent on prepared mixture recipe and extrusion-cooker screw speed [6, 7]. The SME values decreased with higher glycerol content in the mixture (Fig. 4). Furthermore, it was noted, that with increasing the extrusion-cooker screw speed the specific mechanical energy consumption also has been increased. For mixtures with 15% of glycerol content processed at 100 rpm the SME values were 0.068 $kWh \cdot kg^{-1}$. For the same mixtures processed at 80 rpm recorded values were 0.06 $kWh \cdot kg^{-1}$. The lowest values of specific mechanical energy consumption were obtained for mixtures with 30% glycerol content. Studies have shown that during TPS production SME values depend on moisture of prepared mixture [6, 7, 14].

If moisture was higher, SME values were also higher. During the extrusion-cooking of potato starch with 20% of glycerol content and at 20% of moisture content the highest specific mechanical energy consumption was noted (0.076 $kWh \cdot kg^{-1}$).The results for all starches showed that the values of the SME decreased with increased glycerol content in mixture (Fig. 5).

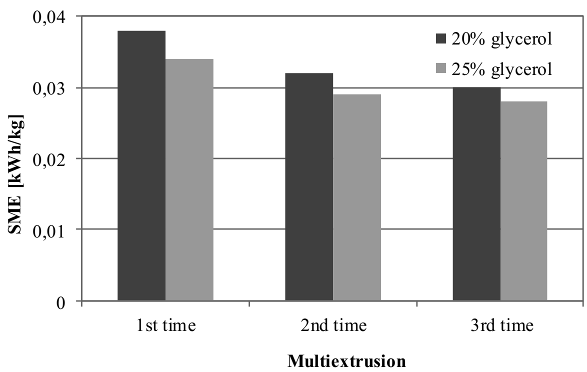

Fig. 6. Values of SME depending on extrusion-cooking repetitions of potato starch

During the potato TPS extrusion-cooking the lowest values of the specific mechanical energy consumption were recorded. The highest SME values were obtained during the extrusion-cooking of wheat starch.

During higher number of extrusion-cooking repetition of potato starch the various values of SME was observed (Fig. 6). If the extrusion-cooking was multiple repeated for the same material, specific mechanical energy consumption was lower [6, 7].

CONCLUSIONS

The obtained results demonstrated that the process efficiency of thermoplastic starch extrusion-cooking decreased with increase of glycerol content in mixture and with higher number of extrusion repetition for the same material. The process efficiency increased with increased of moisture content of potato starch.

The extrusion-cooking of TPS is related with comparatively low energy requirements (0.07 $kWh \cdot kg^{-1}$ on average). During the study it was observed that power consumption during extrusion-cooking depended on the composition of prepared mixtures. The increase of glycerol content in the mixture decreased the specific mechanical energy consumption. SME values were also depending on the screw speed applied during the extrusion-cooking and with multiple repetition of extrusion. The studies indicate the possibility of obtaining optimal values of specific mechanical energy consumption and efficiency of TPS extrusion-cooking.

The obtained results allow for the conclusion that processing of TPS by extrusion-cooking is promising and has to be continued in order to improve production of biodegradable starch packaging materials.

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WYBRANE ASPEKTY PRODUKCJI SKROBI TERMOPLASTYCZNEJ

S t r e s z c z e n i e. W niniejszym artykule przedstawiono wyniki pomiarów wydajności i energochłonności procesu ekstruzji skrobi termoplastycznej (TPS). W trakcie badań stwierdzono, że wydajność procesu ekstruzji TPS zależy w dużym stopniu od ilości plastyfikatora. Wraz ze wzrostem udziału procentowego plastyfikatora w mieszance surowcowej zaobserwowano obniżenie wydajności procesu. Wyższa wilgotność mieszanki surowcowej skutkowała wzrostem wydajności TPS. Wartości SME wynosiły od 0,06 do 0,076 $kWh.kg^{-1}$ i uzależnione były od prędkości obrotowej ślimaków ekstrudera, składu surowcowego oraz krotności ekstruzji skrobi termoplastycznej.

S ł o w a k l u c z o w e: skrobia termoplastyczna, ekstruzja, energochłonność, wydajność.