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EFFECT OF FILLERS ADDITION ON SME OF EXTRUSION-COOKING OF THERMOPLASTIC WHEAT STARCH

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Summary. Results of the SME measurements during extrusion-cooking of thermoplastic wheat starch enriched with flax fibers, cellulose, and ground bark are presented in the paper. A modified single screw extrusion-cooker TS 45 with L / D = 18 and an additional cooling section of the barrel was used as the processing unit. The effect of the quantity and type of filler used in the blend containing 20% glycerol (plasticizer) and the screw speed on the efficiency of the baro-thermal process as well as energy consumption was the main target of the investigation.

Key words: thermoplastic starch, fillers, extrusion-cooking, energy consumption, SME.

INTRODUCTION

The growing amount of deposited waste is a big burden to the environment. Most of plastic waste is resistant to degradation, due to polymers composition. In recent years large-scale studies have been conducted, aiming at increasing the share of starch in starch-plastic composites to the highest level, which resulted in the growth of the production of biodegradable materials used in the packaging industry[3,11].

Thermoplastic starch (TPS) based products are fully degradable and nowadays are successfully used by the rural sector in the field as well as by the food producers for food packaging [2,19]. In order to improve its physical properties and sometimes reduce the price of the finished product different fillers are added to the raw material blends in amounts from 1 to even 50%, dependently on the type of natural fibers used. The most commonly applied fibers are: flax, hemp, jute, coir, cotton, and the waste from wood industry. The important thing is, that the production of TPS-based products is possible with well known machinery and equipment used by plastic manufacturers [10,20].

In the literature many publications can be found concerning the use of starch of different origins for the production of TPS biodegradable packaging materials. Due to the importance of the problem, since 2004 large scale investigations on the processing of TPS biopolimers for packaging materials have been undertaken at the Department of Food Process Engineering, Lublin University of Life Sciences, using corn, potato and wheat starch – the most common local raw materials [1,4,12].

MATERIALS AND METHODS

The basic raw material utilized during the reported study was the wheat starch type MERIZET 200 produced by Segezha Ltd. (IR), mixed with the glycerol of 99% purity, (delivered by Odczynniki Chemiczne Lublin, PL) with the addition of the cellulose fibers vivapur type 102 (JRS GmbH, D), the flax fibers and the ground bark (both delivered by Polish rural producers).

Preparation of the mixtures

The wheat starch (16% of moisture) and other raw materials were mixed in the laboratory ribbon mixer during 20 minutes, than 6 kg samples of different composition were stored within 24 hours in the plastic bags in order to homogenize the mixtures. The share of the glycerol was 20% by weight in the mixture, the contribution of the fibers for selected blends was 0%, 10%, 20% and 30%. Immediately prior to extrusion, the prepared samples once again were mixed for 10 minutes, which guaranteed getting loose structure of the compound [8].

Extrusion

The study was performed using a modified single screw extrusion-cooker type TS 45 (ZMCh Metalchem, PL) with L / D = 18 / 1, equipped with the additional cooling section of the barrel, and a die hole diameter of 3mm. Pellets (Fig. 1) were produced using the screw speed of 60, 80 and 100 rpm. The extrusion process parameters were determined in the temperature range of 60 - 110 ° C and maintained appropriately adjusting the intensity of the flow of cooling liquid. The processing temperature was measured by thermocouples installed along the barrel; the results were recorded. The screw speed was monitored using the electronic tachometer DM-223AR Wireless [8, 16, 17, 18].

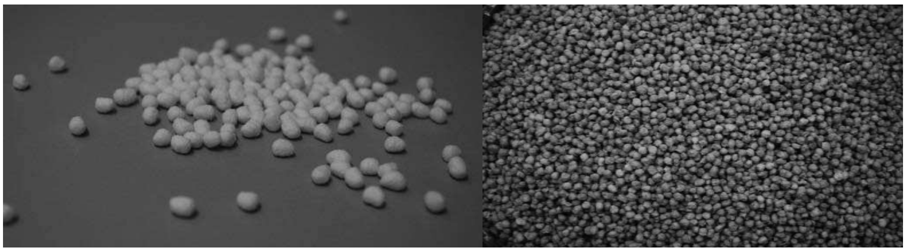

Fig. 1. TPS pellets containing 30% of the cellulose fibers and the flax fibers

The performance testing was conducted by setting the weight of TPS pellets obtained at a given time for all the mixtures of raw materials used processed at the assumed parameters (see formula 1). The measurement was made in six repetitions for each series of tests, their average value was taken as the final result [14, 15].

$$Q = \frac{m}{t} \; [kg \cdot h^{-1}], \quad (1)$$

where: Q – the performance,

m – the mass of the extrudates obtained during the measurement [kg] t - measurement time [h].

The Power measurement was performed using a standard wattmeter connected to the power unit of the extruder. After considering the type of the motor installed in the extruder Shraga TS - 45, appointing the load and resulting in the individual samples, the yield values obtained were converted to the specific mechanical energy index (SME), according to the formula given by Ryu [5, 6, 7, 9, 13]:

$$SME = \frac{N \cdot O \cdot P}{N_m \cdot 100 \cdot Q} \text{ [kWhkg}^{-1}\text{]}, \quad (2)$$

where: N – the screw speed [min^{-1}],
Nm - the maximum screw speed [min^{-1}],
P - power [kW],
O - motor load [%],
Q - output of the extruder [kgh^{-1}].

RESULTS

The performance of the extrusion process was directly proportional to the screw speed, the higher the turnover, the higher yield was obtained. Increasing the cellulose fiber content in the formulations influenced the decline of the process efficiency. The highest yield of 31.8 kg·h^{-1} was determined during the extrusion of pure TPS pellets (without the fillers addition) at the highest screw speed of 100 rpm. Other samples showed a significant impact of the screw rpm on the performance of the extrusion process, regardless of the amount of the additive.

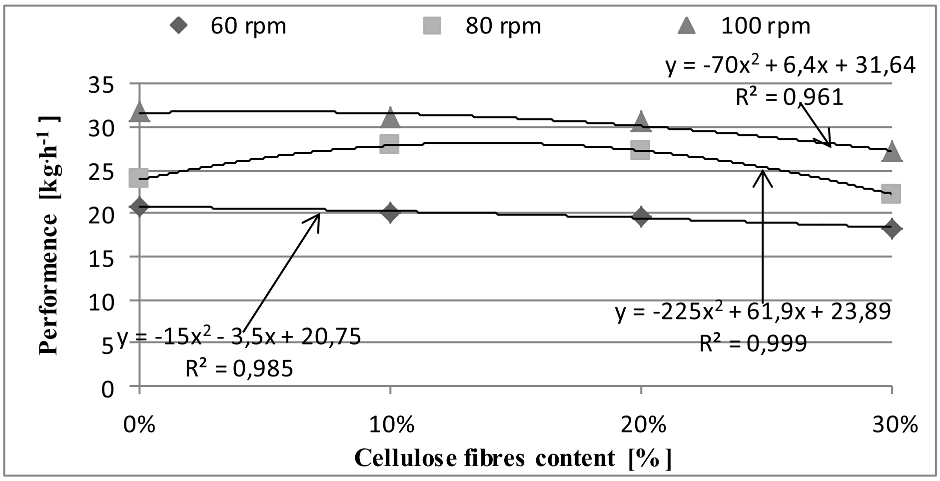

Fig. 2. Effect of cellulose fibers content and the screw speed
on the efficiency of the extrusion of TPS pellets

The lowest yield of 18.3 kg·h^{-1} was observed for the blend containing 30% of the cellulose fibers, processed at a 60 rpm screw speed. A similar trend was observed for the use of a filler in the form of the flax fibers. The efficiency of the process decreased with the increasing of fiber content in the mixture. The lowest yield of 11.64 $kg·h^{-1}$ was registered with the content of 30% flax fibers, processed at 100 rpm of the screw.

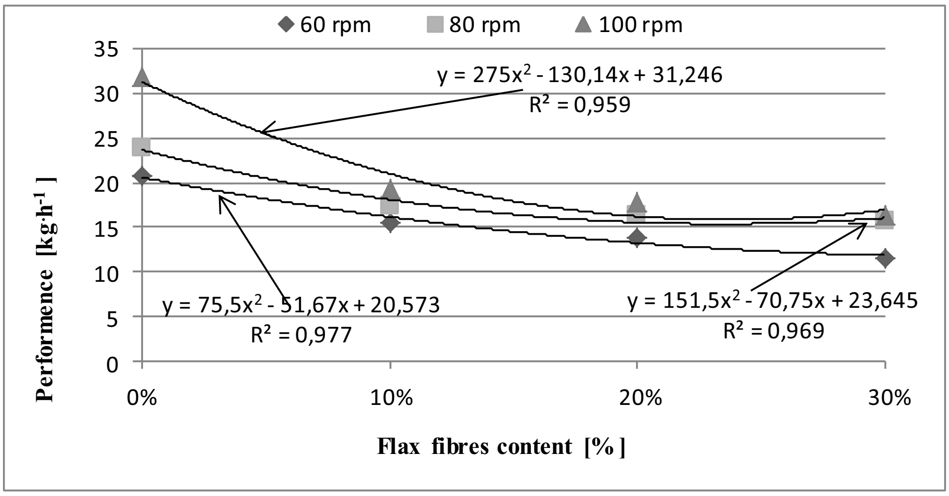

Fig. 3. Effect of flax fibers content and the screw speed on the efficiency of the extrusion of TPS pellets

Addition of the ground bark in all kinds of mixtures resulted in a slight decrease in the efficiency of the extrusion process. Differences between the trial samples were small and amounted to little more than a 1,0 $kg·h^{-1}$.

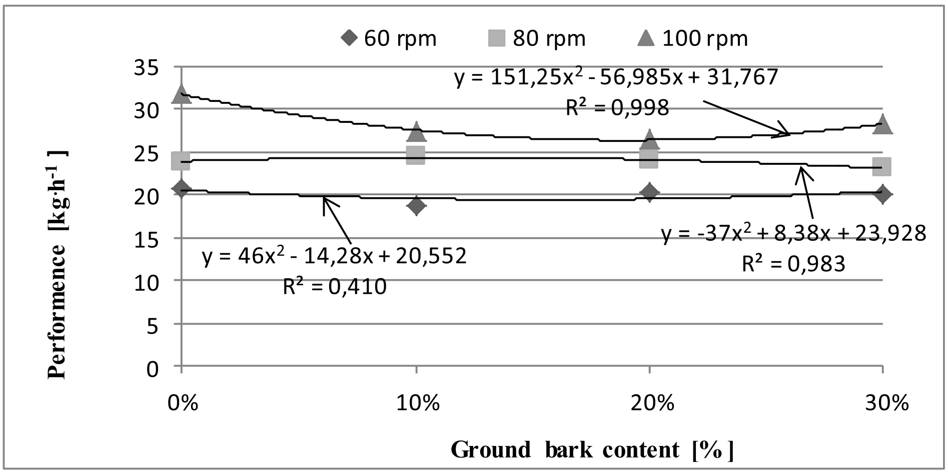

Fig. 4. Effect of ground bark content and the screw speed on the efficiency of the extrusion of TPS pellets

The energy consumption during TPS processing depended on the screw speed used: SME value was higher with increasing of the rotation of the screw.

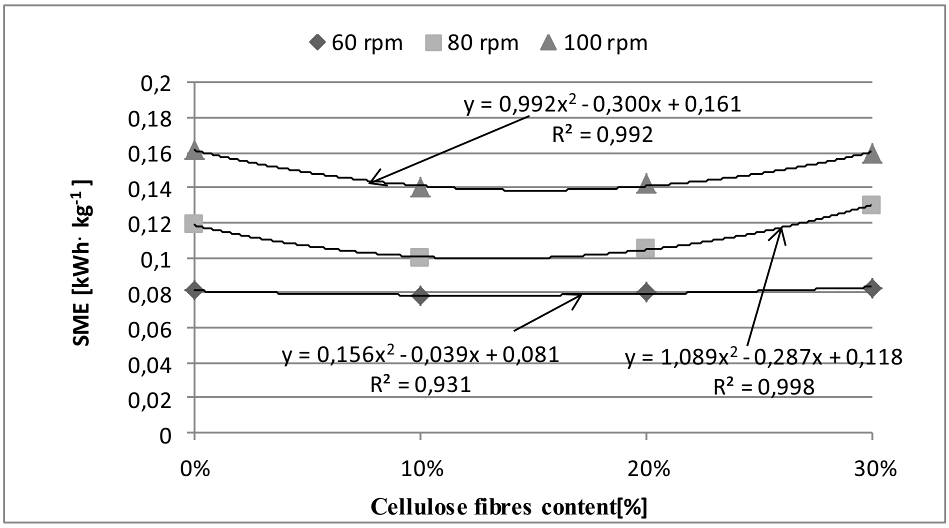

Fig. 5. Influence of cellulose fibers addition and the screw speed on SME

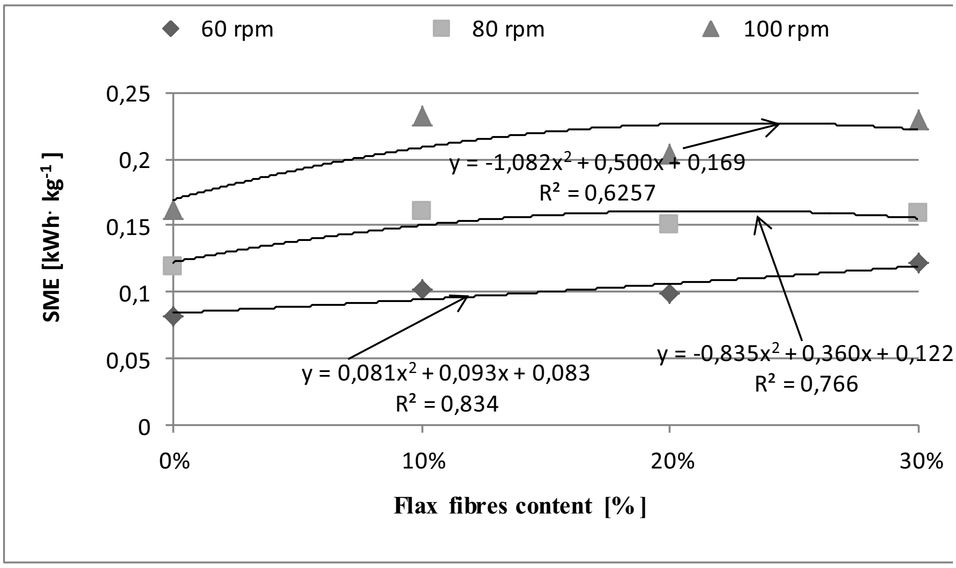

Fig. 6. Influence of flax fibers addition and the screw speed used on SME

SME was similar during the production of biopolymers containing the ground bark and the cellulose fibers. Addition of these fillers had no significant impact on the energy consumption. A bit higher value of the SME was recorded during the production of TPS pellets containing the flax fibers. This is due to the greater length of the flax fibers and hence higher resistance during the extrusion-cooking. The highest SME value of 0.23 $kWhkg^{-1}$ was noticed for the sample containing 30% of the flax fibers, processed at 100 rpm of the screw.

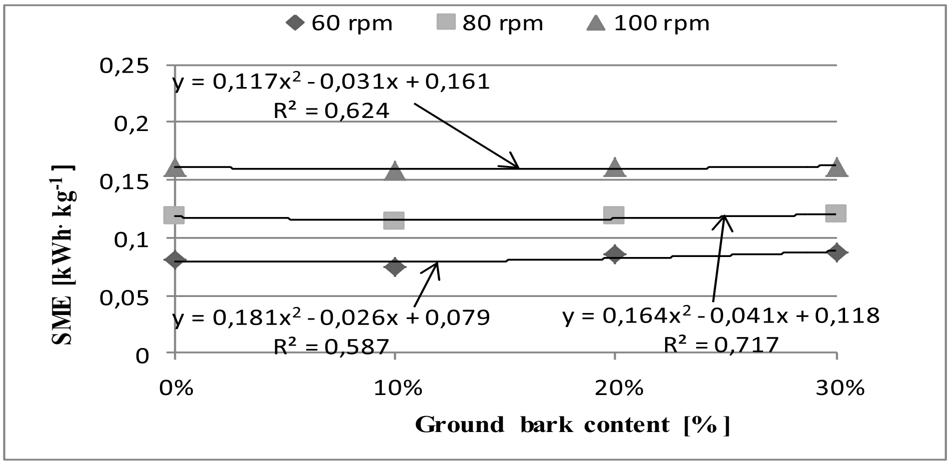

Fig. 7. Influence of ground bark addition and the screw speed on SME

CONCLUSIONS

- The performance of the extrusion-cooking of wheat thermoplastic starch was directly proportional to the screw speed applied; the higher screw rotation - the higher yield was obtained.
- Addition of the fillers affected the performance decrease and the SME increase during extrusion for all blends of raw materials used.
- The value of SME was at a similar level during extrusion of biopolymers containing cellulosic fibers and ground bark.
- The highest energy consumption of 0.23 kWh/kg was noticed in the production of the TPS pellets containing 30% of the flax fibers, processed at 100 rpm of the screw.

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WPŁYW DODATKU WYPEŁNIACZY NA ENERGOCHŁONNOŚĆ EKSTRUZJI SKROBI PSZENNEJ

Streszczenie. W pracy przedstawiono rezultaty badań energochłonności procesu ekstruzji skrobi pszennej wzbogacanej dodatkami funkcjonalnymi. Określono wpływ dodatku wypełniaczy w postaci włókien lnianych, celulozowych oraz mielonej kory na wartość SME. W badaniach zastosowano zmodyfikowany ekstruder jednoślimakowy TS 45 o L/D=18 z dodatkowym chłodzeniem końcowej części cylindra urządzenia. Badano wpływ ilości oraz rodzaju stosowanego wypełniacza w mieszance zawierającej 20% gliceryny (plastyfikatora) oraz wpływ prędkości obrotowej ślimaka ekstrudera na wydajność oraz energochłonność procesu ekstruzji mieszanek skrobi termoplastycznej. Wraz ze wzrostem prędkości obrotowej ślimaka ekstrudera rosła energochłonność oraz wydajność procesu ekstruzji w przypadku wszystkich rodzajów zastosowanych mieszanek surowcowych.

Słowa kluczowe: skrobia termoplastyczna, wypełniacze, ekstruder, energochłonność.