TEKA Kom. Mot. i Energ. Roln. – OL PAN, 2011, 11, 252–260

PRODUCTION OF BIODEGRADABLE PACKAGING MATERIALS BY EXTRUSION-COOKING

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Summary. This paper presents the results of the extrusion-cooking of the thermoplastic corn starch with fillers in the form of flax fibers, cellulose, and ground bark, using the modified single screw extrusion-cooker TS 45 (Polish design) with L / D = 18 and an additional cooling section of the barrel. The influence of the screw speed, the quantity and type of the filler used in the blends containing 20% of glycerol (plasticizer) on the performance and energy consumption of the extrusion process of thermoplastic starch (TPS) is discussed.

Key words: extrusion-cooking, biopolymers, thermoplastic starch, the extrusion-cooker.

INTRODUCTION

Along with economic development and progress of civilization throughout the world, the production of various plastics increases. Nowadays consumers are becoming increasingly sophisticated regarding the quality of products, their appearance and the quality of the packaging. Only a portion of packaging used is recycled, due to high costs and relatively low level of selective collection. The growing amount of the waste deposits is a big burden to the environment. Most of this waste is resistant to degradation, because polymers take a very long time to be decomposed in the environment [1, 4, 10, 18]. The growing awareness of eco-friendly societies and even the fashion for ecology have contributed to the development of research on the so-called biodegradable plastics. Particular attention was paid to the research group of natural materials - biopolymers produced from starch. The biopolymer is obtained after mixing the starch with a plasticizer (glycerol often), to enable the disposal of the material at a temperature lower than the decomposition temperature of starch. This form is called thermoplastic starch (TPS) [13,14,19,20], which may be complementary to alternative plastics. Unfortunately, the products made from TPS do not have wide application because of the utility of certain defects. In order to improve the physical properties of biopolymers and sometimes reduce the price of the finished product, natural fibers can be added in amount from 1 to even 50%, dependently of the fillers used in the mixture. The most commonly used fillers are: flax, hemp, jute, coir, cotton, and the waste from wood industry. The large-scale studies aiming at the increasing of the share of TPS in the production of packaging materials have been undertaken in recent years. Nowadays, a substantial growth of biodegradable materials application is noticed during the production of various products. These products are more and more present in our houses, and manufacturers are constantly looking for newer and better technologies for their production. In addition, the fact that they can be fully degradable solves a problem for the storage of used packaging. When properly treated, they can be composted and used for agricultural or horticultural purposes. In the anaerobic process they can produce the methane gas, further used for heating or as a propellant [2,3,5,11].

MATERIALS AND METHODS

The study was performed using the single screw extrusion-cooker TS-45 (Polish design), equipped with an additional cooling system of the barrel, L / D = 18 / 1, the die of 3mm diameter, and a screw rotation 60, 80, 100 rpm (Fig. 1). Extrusion-cooking process temperature ranged from 60 till 110°C, which was determined by appropriately adjusting the intensity of the flow of cooling. The electronic tachometer DM-223AR Wireless was used to measure the screw speed; the processing temperature was measured by thermocouples installed in the barrel of the extruder, registered on the control panel.

The main component was corn starch, mixed with the glycerol (the plasticizer) and fillers in the form of: cellulose fibers, flax and ground bark, added to improve the quality of the TPS. A technical glycerol of 99% purity was added to all the prepared blends in the quantity of 20% in contrary to the fillers, which were added selectively with 0, 10, 20, and 30% content of the whole mixture weigh. The blends were mixed for 20 minutes in a laboratory ribbon blender until a homogeneous mass. After mixing, the samples were stored in sealed plastic bags for 24 hours in order to increase the penetration of the glycerol in the starch grains. Immediately prior to extrusion, the blends were again mixed for 10 minutes, which ensured obtaining a uniform and powdery mixtures fed into the extruder.

Fig. 1. Modified single screw extrusion-cooker TS-45, equipped with electric heaters and air-water cooling system of the barrel

The performance of the extrusion-cooking was conducted by setting the weight of extrudates obtained at a given time for all the mixtures of raw materials used, processed at the assumed parameters. The performance measurement was made using an electronic timer and the WPS 210 weight in six repetitions for each series of the tests. The performance was determined by the following formula [15,16,17]:

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

where:
Q - performance,
m - mass of the extrudate obtained during the measurement [kg]
t - measurement time [h].

The energy consumption measurement was performed using a standard Wattmeter connected with the power unit of the extruder. After considering the type of the Shraga motor installed in the extruder, appointing the load and resulting in the individual samples, the yield values obtained were converted to specific mechanical energy (SME), accordingly to the formula given by Ryu [6,7,8,9,12]:

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

where:
N – the screw speed [min^{-1}],
Nm - the maximum screw speed [min^{-1}],
P - Power [kW],
O – the motor load [%],
Q – the output of the extruder [$kg \bullet h^{-1}$].

RESULTS

During tests the significant effects of the screw speed on the efficiency of the extrusion-cooking process were observed. The performance of the extrusion process was directly proportional to the screw speed: the higher rotational speed - the higher yield was obtained. Increasing the cellulose fiber addition in the formulations influenced the decline in raw material efficiency of the extrusion process.

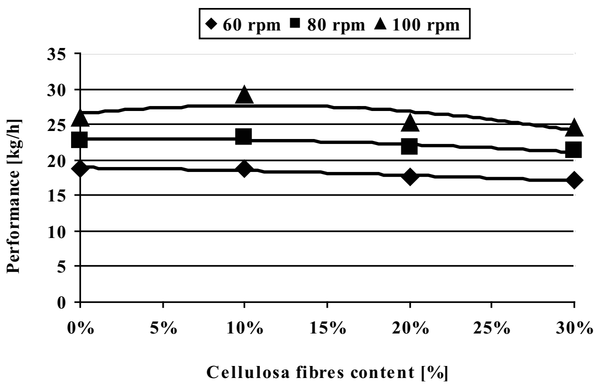

Fig. 2. The effect of the cellulose fiber's content and the screw speed on the performance of the extrusion process

Table 1. Evaluation of the results presented in Fig. 2.

Skrew rpm	Regression equations	R^2
60	$y = -4x^2 - 4,12x + 18,968$	0,81
80	$y = 75,25x^2 - 19,205x + 23,15$	0,55
100	$y = -44x^2 + 17,88x + 26,218$	0,74

The lowest yield of 17.5 $kg{\cdot}h^{-1}$was obtained during extrusion of the samples containing 30% of cellulose fibers, processed at the lowest screw speed (60 rpm). The increase of the screw speed resulted in a slight increase efficiency of the extrusion process, despite the growing number of cellulose fibers in the blend.

Addition of flax fibers resulted in the decline in the productivity during the extrusion process used for all blends. This was due to the greater fiber length, and the lower degree of mixing of the sample. During the processing problems appeared with the dosing of the mixture - the material blocked the inlet easily. The lowest yield of 11.28 $kg{\cdot}h^{-1}$was obtained during the TPS extrusion, using the additive of 30% flax fibers, processed at the lowest screw speed of 60 rpm. Increasing the fiber content in the mixture of raw flax did not have any major impact on the performance of the extrusion process. Differences between trials were minor.

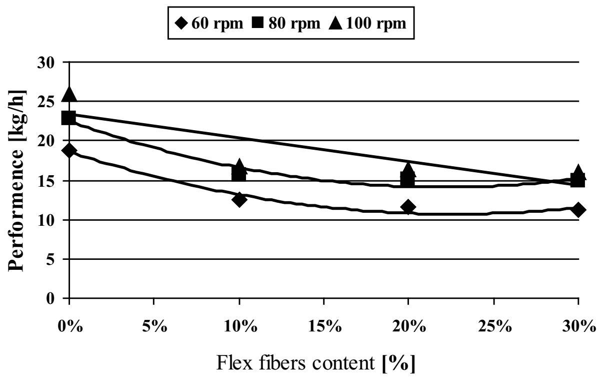

Fig. 3. The effect of the flax fiber's addition and the screw speed on the performance of the extrusion process

Table 2. Evaluation of the results presented in Fig. 3.

Skrew rpm	Regression equations	R^2
60	$y = 154x^2 - 69,8x + 18,6$	0,97
80	$y = 173x^2 - 76,22x + 22,493$	0,95
100	$y = -30,24x^2 + 23,376$	0,66

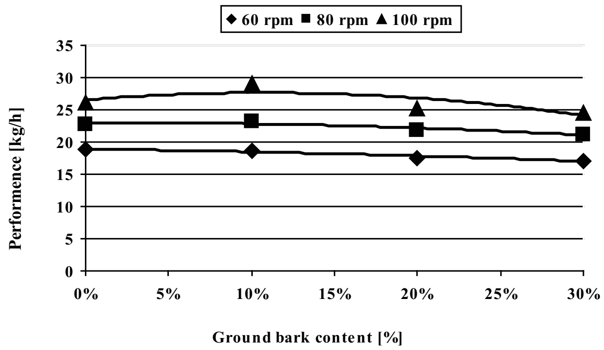

Fig. 4. The effect of the ground bark's addition and the screw speed on the performance of the extrusion process

Table 3. Evaluation of the results presented in Fig. 4.

Screw rpm	Regression equations	R^2
60	$y = -9,25x^2 - 3,535x + 18,922$	0,94
80	$y = -24,75x^2 + 1,115x + 22,962$	0,82
100	$y = -96x^2 + 20,64x + 26,544$	0,58

Similar trend was observed in the case of the blends containing 10% of the filler (ground bark and cellulose fibers). The productivity of the extrusion was bigger when fewer fillers were present. The highest yield of 29.16 $kg \cdot h^{-1}$ was obtained for blends containing 10% of the ground bark at top screw speed; the lowest yield of 17.1 $kg \cdot h^{-1}$ was achieved with the participation of 30% in the mixture, processed at the lowest speed of 60 rpm.

When using the extrusion-cooking technology for processing of TPS, one of the most important factor is to determine the specific mechanical energy (SME) required to obtain the unit mass of the product.

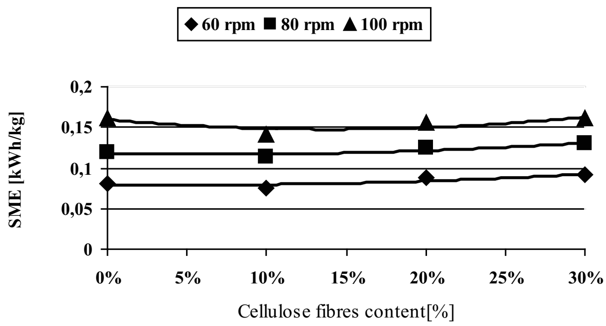

Fig. 5. Influence of the cellulose fiber's content in the mixture and the screw speed on SME

Table 4. Evaluation of the results presented in Fig. 5.

Skrew rpm	Regression equations	R^2
60	$y = 0,221x^2 - 0,024x + 0,079$	0,73
80	$y = 0,248x^2 - 0,03x + 0,117$	0,82
100	$y = 0,598x^2 - 0,167x + 0,159$	0,57

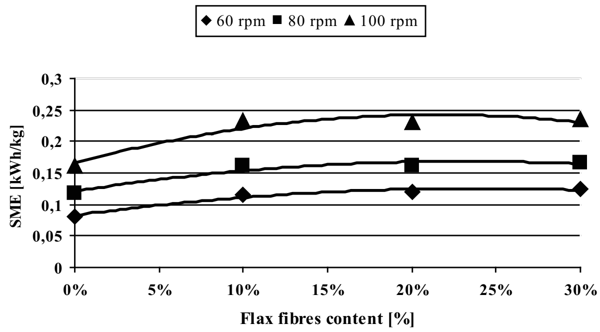

Fig. 6. Effect of the flax fiber content in the mixture and the screw speed on SME

Table 5. Evaluation of the results presented in fig. 6.

Skrew rpm	Regression equations	R^2
60 obr·min^{-1}	$y = -0,741x^2 + 0,355x + 0,083$	0,94
80 obr·min^{-1}	$y = -0,899x^2 + 0,413x + 0,1211$	0,91
100 obr· min^{-1}	$y = -1,662x^2 + 0,714x + 0,1659$	0,90

During the extrusion process of the thermoplastic corn starch it was noticed that the energy consumption was growing with the increasing of the screw speed. The highest SME was recorded during the production of TPS pellets containing the flax fibers. This is due to greater length of the flax fibers and hence higher resistance during baro-thermal treatment, however its amount did not significantly affec the final value of the SME. The lowest value of the SME was measured during the extrusion of the samples without addition of the flax fibers (0.08 kWh•kg^{-1}), and the highest of 0.23 kWh•kg^{-1}for the sample containing 30% of the flax fibers processed at 100 rpm of the screw.

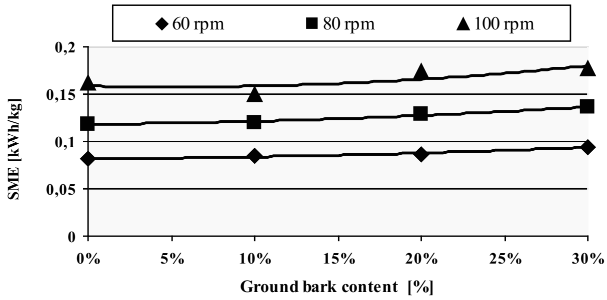

Fig. 7. Influence of the ground bark content and the screw speed on SME

Table 6. Evaluation of the results presented in Fig. 7.

Skrew rpm	Regression equations	R^2
60	$y = 0{,}094x^2 + 0{,}012x + 0{,}081$	0,98
80	$y = 0{,}148x^2 + 0{,}017x + 0{,}118$	0,98
100	$y = 0{,}362x^2 - 0{,}037x + 0{,}158$	0,62

SME measurement during the production of TPS containing cellulosic fibers and ground bark showed similar tendency. The value of SME during processing of the blends containing the ground bark was higher by 0.02 kWh•kg^{-1} than the blends with similar addition level of the cellulose fibers. The highest value of SME of 0.15 kWh•kg^{-1} was recorded during the extrusion of the samples containing cellulose fibers at 80 and 100 rpm of the screw.

CONCLUSIONS

Based on the obtained results the following conclusions can be made:

- The performance of the extrusion-cooking process was directly proportional to the screw speed; the higher rotational speed resulted in the higher capacity of the process.
- Addition of the flax fibers caused a decrease in the process efficiency for all the mixtures of raw materials used.
- 10% addition of the cellulose fiber, and the ground bark in the compound increased the efficiency of the extrusion process, while higher amount of the fillers to the level of 20 and 30% resulted in its decline.
- During the extrusion-cooking of TPS containing cellulosic fibers and ground bark the value of SME was at a similar level.
- The highest energy consumption was noticed in the production of TPS blends containing the flax fibers. That happened due to the length of the fibers and residence occurring during the processing.

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PRODUKCJA BIODEGRADOWLNYCH MATERIAŁÓW OPAKOWANIOWYCH METODĄ EKSTRUZJI

Streszczenie. W pracy przedstawiono rezultaty badań wpływu dodatku wypełniaczy w postaci włókien lnianych, celulozowych oraz mielonej kory na proces ekstruzji skrobi kukurydzianej. W badaniach zastosowano zmodyfikowany ekstruder jednoślimakowy TS 45 o L/D=18 z dodatkowym chłodzeniem końcowej części cylindra urządzenia. Badano wpływ prędkości obrotowej ślimaka ekstrudera, ilości oraz rodzaju stosowanego wypełniacza w mieszance zawierającej 20% gliceryny (plastyfikatora) na wydajność oraz energochłonność procesu ekstruzji mieszanek skrobi termoplastycznej.

Słowa kluczowe: ekstruzjia, biopolimery, skrobia termoplastyczna, ekstruder.