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INVESTIGATIONS OF THERMOPLASTIC STARCH EXTRUSION COOKING PROCESS STABILITY

Marcin Mitrus

Department of Food Process Engineering, Agricultural University of Lublin
Doświadczalna Str. 44, 20-236 Lublin, Poland,
e-mail: marcin.mitrus@ar.lublin.pl

Summary. Results of thermoplastic starch (TPS) extrusion cooking process stability investigations are presented in the paper. Research showed that the use of additional cooling system in modified single screw extruder TS-45 allowed to keep constant process temperature for almost all the trials at the appropriate level within the range 80–100°C. There was recorded an evident influence of the screw rotation speed, the mixture composition and the moisture content of raw materials on temperature profile along the barrel of the extruder. It was found out that changes of the TPS temperature at the slit die depended predominantly on the screw rotation speed used.

Key words: thermoplastic starch, extrusion cooking, process stability

INTRODUCTION

An interest in starch as material to be incorporated into packaging industry was recorded to rise drastically in the 1970`s along with the growth of ecological awareness of the society. Quite important proved to be a possibility to reduce manufacture cost of synthetic plastics due to relatively low starch price.

Unfortunately, the materials obtained from traditional synthetic polymers with addition of starch are not fully biodegradable. After starch biodegradation, they undergo only strong fragmentation into small pieces that occasionally gives an impression of material disappearance.

Considering both the fact that starch biodegrades to carbon dioxide and water in a relatively short time compared with most synthetic polymers, and some drawbacks of the existing technologies of biodegradable materials manufacture, in the recent years there have been started large-scale researches to increase amount of starch in starch-plastic composites to the highest possible level. The final objective of these investigations is to obtain disposable commercial items produced from pure starch and to exclude synthetic polymers from the formulation. Thermoplastic starch (TPS) seems to be perfect solution that can be processed with conventional technologies used in synthetic plastic manufacture (extrusion, injection moulding) [Wiedmann *et al*. 1991, Shogren *et al.* 1993].

MATERIALS AND METHODS

Materials

The basic material for investigations was made by 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.

To make comparative studies there were used 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.

Glycerol of 99% purity was used in the tests as a plasticizer, being added in the amount of 15–30% of starch dry mass [Mitrus 2005b, 2006].

Blend preparation

All the starch types were blended and, after their mixing and damping, made 20 kg of the sample material. As a result of the repeated trials there was established the effective agitation time in a bakery kneading pan, i.e. 20 min, that assured loose and friable blend structure.

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

The prepared mixtures were delivered to the feeding device of the modified extruder to undergo baro-thermal treatment [Mitrus 2005b, 2006].

Extrusion cooking

The preliminary investigations on starchy biopolymers extrusion cooking were run on a standard food extruder TS-45 produced by Z.M.Ch. Metalchem in Gliwice equipped with the plastifying system L/D = 12/1. Unfortunately, the trials demonstrated this apparatus uselessness because of the too "short" plastifying system. During the extrusion process the material was not processed in full, too high temperatures inside the extruder cylinder along with high pressure extrusion resulted in excessive expansion and formation of steam bubbles in a product.

This observation was confirmed by many authors who hold that for TPS extrusion cooking so called „long" plastifying systems should be applied with L/D ≥ 16 [Aichholzer *et al*. 1998, Yu *et al*. 1998, Shogren 1992, Lörcks *et al*. 2001, de Graff *et al*. 2003, You *et al*. 2003,].

Therefore a modified version of extruder TS-45 was used fitted with a new plastifying system of L/D = 16/1 as well as additional cooling system of the final cylinder part. 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 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 high-speed cutter for chopping a product to the granulate of fixed, small dimensions. To avoid granulate sticking together there was installed additional cooling of the extrudate discharged from the crosshead by a nozzle with compressed air assembled at the crosshead top [Mitrus 2005a].

Process stability

Stability of the process course was evaluated on the basis of recorded temperature changes in each extruder section over the processing of all the applied materials and process parameters. Stability of temperature behaviour of a final product was also studied immediately after it left the extruder die. The temperature was measured in the cylinder by means of thermocouples fixed in each section and connected to meters installed in the extruder control board. The product temperature was recorded with digital thermometer CIE 370 type equipped with appropriate measuring lance. All the data were registered in the accessory set based on PC work.

Feeding stability and mass flowing through the cylinder and extruder crosshead were assessed by recording and evidence of extruder shutdowns, problems with material feeding and die openings blocking. These data are of great importance to fix the optimal parameters for TPS production taking into account production stability maintenance as well as invariable process parameters, in particular at the long production cycles.

RESULTS

The use of a modified extruder TS-45 equipped with additional cooling system allowed to keep the process temperature for almost all the trials at the appropriate level within the range 80–100°C. There were detected slight mean fluctuations of temperature at each extruder section at TPS extrusion for all the starch types (fluctuations ±5°C). There was recorded an evident influence of screw rotation speed, mixture composition and its moisture on temperature changes at all the extruder sections (Fig. 1 and 2).

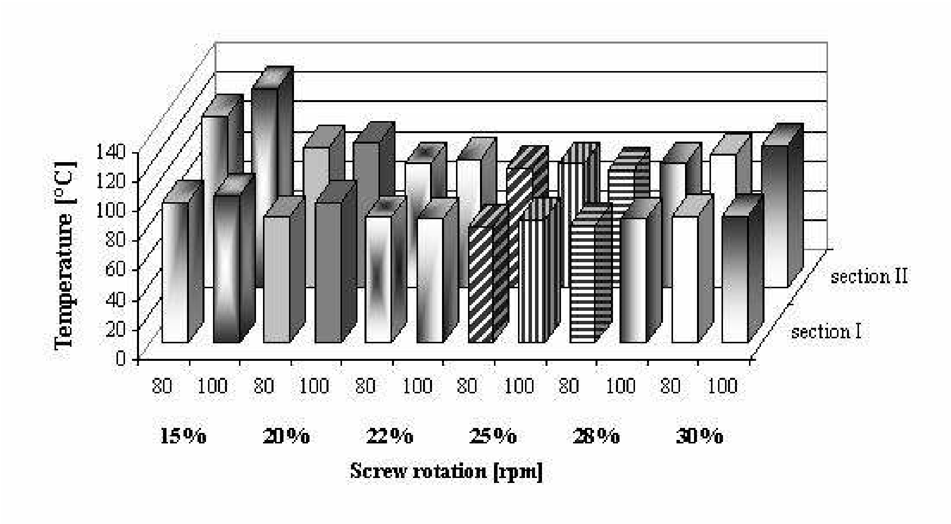

Fig. 1. Temperature changes course over the extrusion of potato TPS with varied glycerol content for different screw rotation speeds

The temperature growth was observed with an increase of screw rotation speed and it was the highest for the mixtures at the lowest moisture (15%) and glycerol content

(15%). This effect was brought about by heat friction inside the cylinder and exchange of mechanical energy into heat one.

Along with glycerol content increase up to 25% in the mixtures there was noted temperature fall at all the extruder sections (Fig. 1). The processing of mixtures with increased glycerol content induced temperature rise at the full length of the plastifying system.

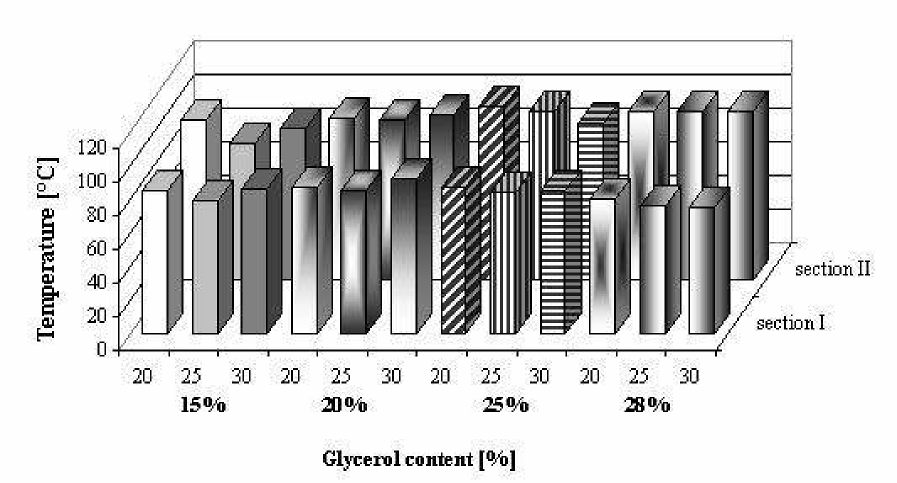

Fig. 2. The course of temperature changes at the extrusion cooking of potato thermoplastic starch with varied glycerol contents for different mixture moisture at 80 rpm screw rotation speed

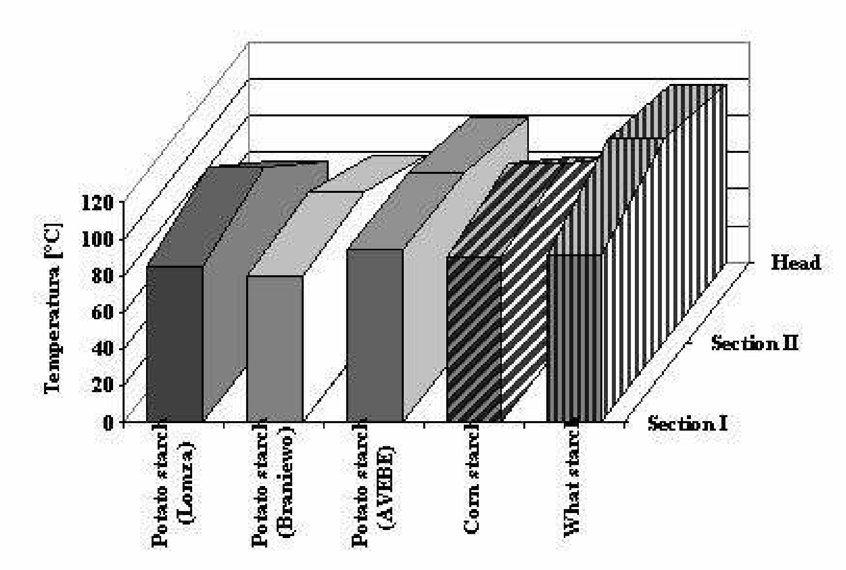

Fig. 3. Temperature distribution at extrusion cooking of different starch types with 20% glycerol content

A reverse impact on the extrusion temperature changes was noted in case of changes of material moisture (Fig. 2). Together with mixture moisture rise up to 25%

there was recorded temperature growth at all the extruder sections. However, above this value there was recorded an insignificant temperature increase.

An influence of starch applied on the TPS granulate temperature is presented in Fig. 3 and 4. It was found out that the highest extrusion temperatures, regardless of glycerol content, were obtained for wheat starch, while the lowest ones for potato starch. Throughout the granulate manufacture with potato starch use of varied amylose content the extrusion process proceeded in a more stable way in case of the mixtures with potato starch of the highest amylose content.

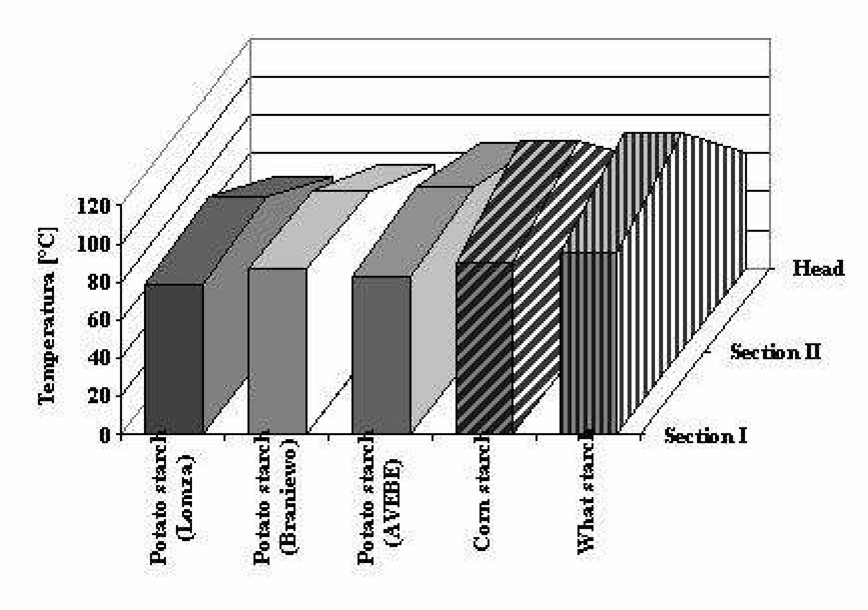

Fig. 4. Temperature distribution at extrusion cooking of different starch types with 25% glycerol content

During the investigations in case of material mixtures there was noted material arching in the extruder charging hopper and some difficulties with material delivery by the screw. Due to these reasons it was necessary to feed the material in manually. The disturbances with uniform material feeding induced uncontrolled changes of extrusion cooking temperature, even by ±20°C. At failure of material feeding or its reduction, the temperature at the extruder sections dropped, to be followed by a drastic rise after the feeding in restart. The temperature changes caused excessive TPS expansion, steam bubbles formation and granulate surface destruction. For the blends with glycerol content over 20% there was also recorded granulate stickiness that prevented its separation. To avoid this effect the material needs to be fed in thoroughly and precisely, thus carefully controlling its flow and delivery to the screw.

Water content over 15% in blends brought about an excessive expansion of the obtained granulate. The extrudate showed a damaged surface with numerous steam bubbles. The application of the extended extruder variant TS-45 with the final part of the cylinder cooling system by means of variable flow of cold water definitely improved the stabilization of the final product. The maximal water flow through the refrigeration installation of the cylinder final part was 400 l/h and was used at the processing of the maize and wheat starches as well as potato starch mixtures with 15% glycerol content. In other cases the water flow was 140–370 l/h.

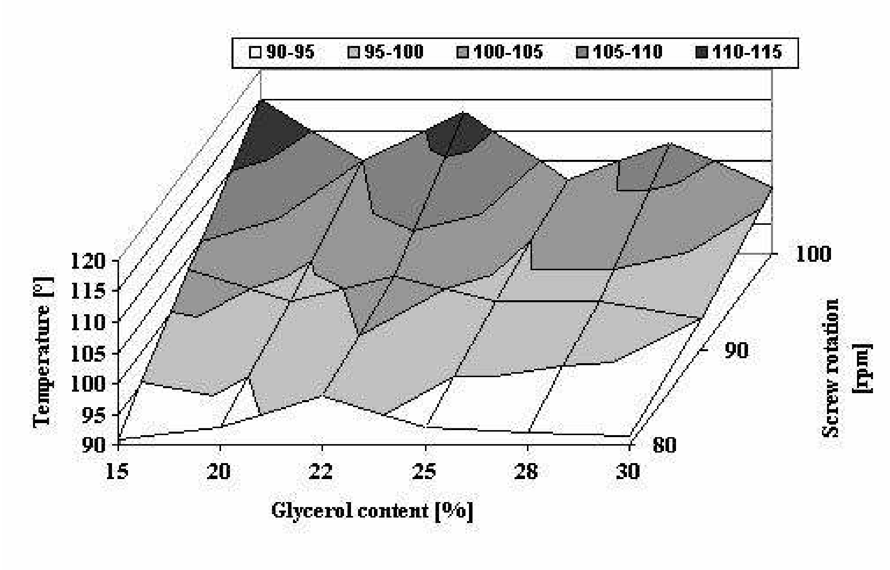

Fig. 5. Potato TPS temperature at die opening in relation to glycerol content and screw rotation speed.

It was found out that changes of the TPS temperature at the slit die depended predominantly on the applied screw rotation speed. Irrespective of moisture and mixture composition, if screw rotations increase, the temperature of the final products grows (Fig. 5). The temperature of TPS produced at 100 rpm was higher by even 9–24°C compared to 80 rpm. Along with glycerol content growth in material mixture there was noted a temperature drop of the product leaving the die. For 80 and 90 rpm screw speed the product temperature changed in a small range of ±5°C. However, at 100 rpm application the fluctuations of the product temperature reached even 12°C.

CONCLUSIONS

The application of the modified single screw extruder TS-45 produced by Z.M.Ch. Metalchem in Gliwice (PL), fitted with extended plastifying system as well as additional cooling system proved to be useful for extrusion cooking of TPS. TPS granulates can be used for the manufacturing of biodegradable packaging materials (e.g. films). The use of additional cooling system allowed to keep the process temperature for almost all the trials at an appropriate level within the range 80–100°C.

There was recorded an evident influence of the screw rotation speed, the mixture composition and the moisture content of raw materials on temperature profile along the barrel of the extruder. Changes of the TPS temperature at the slit die depended predominantly on the applied screw rotation speed.

It was stated that the applied range of thermal treatment of potato starch running from 80–100°C and the extruder screw rotation range 80–100 rpm allowed getting a good quality product without any visible damage or steam bubbles. Granulate produced from wheat and corn starch blends with glycerol addition at the same conditions has not met the required quality parameters to the full.

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