THE ROLE OF WATER ON THE EXPANSION INDEX OF STARCH BASED PACKING PEANUTS

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Abstract

Thermoplastic extrusion has been used to produce starch-based packing peanuts, in a similar way to the production of extruded expanded snack foods. Native starches are non-plastic due to the intra- and intermolecular hydrogen bonds between the hydroxyl groups in starch molecules, which represent their crystallinity. Thermo-mechanical processing is used to disrupt and transform the semi-crystalline structure of starch granules to form a homogeneous and amorphous material. This transformation is usually accomplished using small amounts of molecular substances commonly known as gelatinization agents or plasticizers. This paper presents some aspects of producing packing peanuts based on starch by means of thermoplastic extrusion, putting an emphasis on the working diagram describing the extrusion mechanism with direct expansion of a partially crystalline polymer and the mechanism of extrudate expansion with aplication to the influence of water content on the expansion index.

Key words: packing peanuts, starch, water, expansion index

Conventionally, expanded plastic materials are obtained by making a composition more fluid, forming cell structure with the help of a clearing agent and solidifying the composition while maintaining the cell structure in the final product.

Figure 1 shows the working diagram for the extrusion process with direct expansion of a partially crystalline polymer (Strahm, B., 1998).

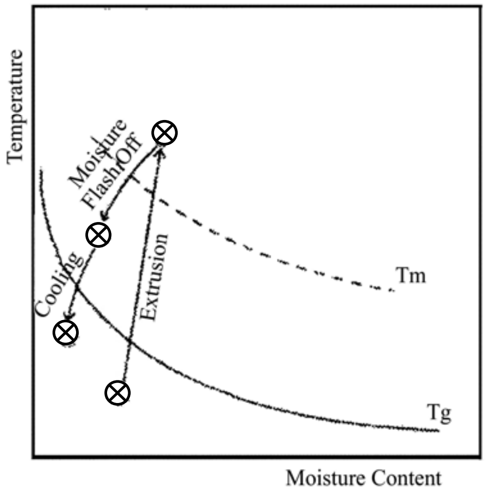

Figure 1 **Working diagram during extrusion with direct expansion**

One can notice on the diagram the transformations suffered by the raw material while heated and cooled down, due to its passing through the vitreous transition temperature Tg and melting temperature Tm. As seen in the same diagram, Tg and Tm are influenced by the composition moisture content.

Analysing the operation of the extruder for direct extrusion according to diagram in figure 2, we find that heated starch turns from the glassy state at feeding to a highly elastic state and then to melted state before getting into the die. After leaving the die, expansion occurs by suddenly diminishing moisture. With the loss in moisture, temperature loss takes place and the extrudate

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returns to its highly elastic state and then to the amorphous state. In fact, when the extrudate temperature decreases under Tg, expansion stops and the structure of the extrudate stabilizes.

Many studies try to model the extrudate expansion, mainly from the perspective of the influence of the material and process parameters.

It is for this reason that it is crucial to understand the basic phenomenon of the complex mechanism governing the expansion of the cereal matrix, a mechanism that incorporates both materials properties and process parameters. Though there are many papers related to the quantitative development mechanism in the expansion during extrusion of synthetic polymers (i.e. of the formation of the polymer foam), few works deal with the polymer expansion. This can be accounted to the complexity of such systems undergoing continuous transformations during extrusion.

However, there are studies on the modelling of expansion in the food extrusion. But many of them make use of simplifying hypotheses for the development of these models.

The diagram from figure 2 shows the various stages in expansion and illustrate the extrudate expansion mechanism (Moraru C.I., Kokini J.L., 2003).

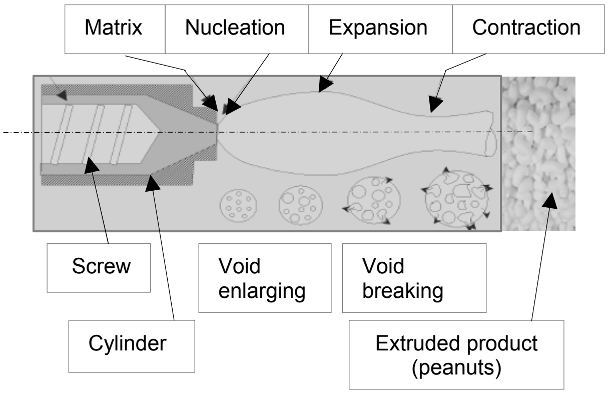


Figure 2 **Diagram of the expansion of the extrudate**

The mechanism of the expansion of the extrudate comprises five steps: order-disorder changes, nucleation, extrudate swelling, void enlarging and void breaking.

First, intense shearing, the pressure and temperature inside the extruder, lead to changing the raw material (the corn flower) in a viscous-elastic melt. The transformation degree depends a lot on the content of moisture and working extruder parameters.

Void nucleation, i.e. germ initiation or crystallization nuclei inside the polymer melt, is performed during extrusion both where small air voids or impurities appear during the extrusion process as well as in the voids representing the free volume of polymer during feeding.

These voids enlarge when the melt leaves the die due to the expansion process developed by the moisture in the void when the high pressure of the overheated steam generated by nucleus water steaming exceeds the mechanical strength of the viscous-elastic melt surrounding it. The voids stop enlarging when cooled down, when the viscous-elastic matrix becomes amorphous and the shape and size of the extrudate become final.

MATERIAL AND METHOD

The normal corn starch used in this study was obtained from SC Amylon SA Sibiu, Romania. The initial water content of starch on dry wet was 12%. The other characteristics of this starch, supplied by the manufacturer are shown in table 1.

Table 1
The physicochemical characteristics of corn starch

Ash	Protein	Density	Viscozity
max. 0.1%	max. 0.5%	0.561 g/cm^3	700 UB (10 min la 95 ^{0}C)

Structure of utilised starch granules was determined (M. Tomoaia-Cotisel, et al., 2010).

The glycerol used in formula was purchased from SC Nordic Invest SRL Cluj Napoca The glycerol had a concentration of 99.5% and a density of 1.262 g/cm^3.

The water used was from the water supply system.

The table 2 indicate the ratio of the two components in the formula, based on which have been established the starch and plasticizer flow rate.

Figure 3 shows a schematic representation of a utilized packing peanuts extrusion system.

Table 2
The ratio of components in the formula

Formula abbreviation	Water [% wet basis]	Glycerol [% wet basis]
ATN 411	16.66	16.66
ATN 412	14.29	28.57

A laboratory twin-screw extruder with co-rotating intermeshing, self-wiping screws (Model ZK 25, Collin) was use to conduct the extrusions. The extruder has a maximum productivity of 15 kg/h, 25 mm screw diameter, 30:1 length to diameter ratio, max. 400 rpm screw speed and six independent electric heating and cooling areas. The first area of the extruder, which is the supply area, is not heated, but can be cooled with water. The two to five areas are provided with electric heaters and cooling fans.

Each of these five areas is equipped with one temperature sensor that measures temperatures and control starting or stopping of the heaters or fans to maintain temperatures set in each area.

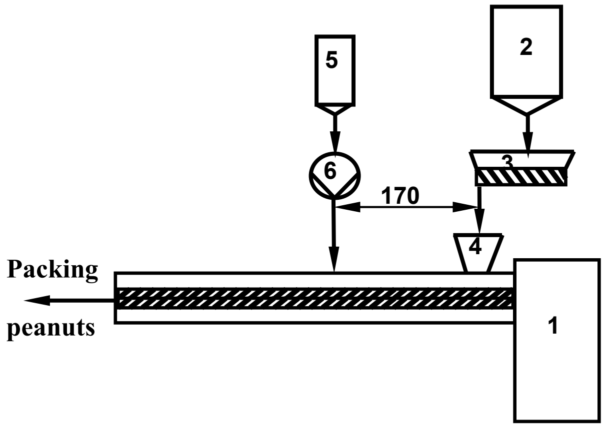


Figure 3 **Schematic representation of a foaming extrusion system**

1 - Extruder; 2 - Starch tank; 3 - Starch feeder;
4 - Starch feeding hopper; 5 - Plasticizer tank;
6 - Plasticizer feeding pump

The six area of the extruder is the die area - it has its own heater, and no cooling. Its temperature is measured and maintained at the value initially established by the temperature sensor. Also in the die area there are another two sensors that are in direct contact with the material that is processed and measuring its temperature and pressure. These two parameters are very important, for them relying largely the quality and cross size of the extruded product.

Temperature values in these six areas of the extruder are initially set, achieved and maintained during extrusion plant operation with a program whose interface is the control panel of the extruder.

The starch was feed into the extruder hopper with a single screw volumetric feeder. The feeder can achieves starch flow rates ranging from 0.481 kg/h to 5.220 kg/h.

The dosing pump used to feed the plasticizers from the plasticizers tank was a low capacity and high dosing precision peristaltic pump (Model PERIPUMP D'5187, MTA KUTESZ, Hungary), with max. 42 ml/min flow rate. In order to use a single dosing pump both plasticizers (glycerol and water) being miscible, were mixed in the proportion of the formula and placed in the plasticizers tank.

Preliminary study indicated that the premixing starch powder and plasticizers tended to cause bridging in the feeding hopper. Therefore the plasticizers were added into the working area through a pipe connection located at 170 mm from axis of the supply hopper (fig. 1).

The screw speed was set at 220 rpm and the barrel temperatures were maintained during the experiment at 30, 50, 100, 130, 150 and 150^0C, respectively, from the feeding port to the die section. For the used formulas, the glass transition temperature was 73 ºC to ATN411 mixture and 71 ºC to ATN412 mixture.

A circular die plate with one hole was use. The diameter of the hole in the die is 3 mm.

The extruding product was collected and cooled to room temperature. At each experiment samples were taken after the extruder had reached steady state.

RESULTS AND DISCUSSIONS

In the table 3 and table 4 there are presented the results of the experiments for the two recipes used.

The expansion index was calculated as the ratio between the section of the extrudate and the section of the die hole.

Table 3

The aspect of the samples after extrusion

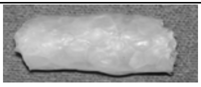
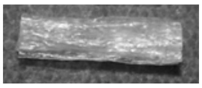
Sam-ple	Symbol	Weight ratio		The aspect of the samples after extrusion
1	ATN 411	starch	4	
		water	1	
		glycerol	1	
2	ATN 412	starch	4	
		water	1	
		glycerol	2	

Table 4

Expansion index

Sample	Symbol	Extrudate`s diameter [mm]	Diameter of the die hole [mm]	Expansion index [%]
1	ATN 411	13	3	21.7
2	ATN 412	7	3	5.4

CONCLUSIONS

Thermoplastic extrusion provides for the required changes in producing of starch based packing peanuts.

The expansion is better when melting nears full melting, dispersion is larger and homogeneity improved.

Nucleation contributes in a decisive manner to expansion. The air/based cell structure of expanded extrudates seems to be in tight connection with the number of voids nucleated in the starch melt. The increase of voids takes place because of the difference in pressure inside and outside the voids. This increase is extremely considering its influence upon the structure and texture of the expanded material.

The expansion index decrease with decreasing the water/glycerin proportion in the recipe.

BIBLIOGRAPHY

Strahm, B., 1998 - *Fundamentals of Polymer Science as an Applied Extrusion Tool*. Cereal Foods World, 43(8), p. 621-625.

Moraru, C.I., Kokini, J.L., 2003 - *Nucleation and Expansion during Extrusion and Microwave*, în Comprehensive Rewiews in Food Science and Food Safety.

Tomoaia-Cotisel, M. et al., 2010 - *Structure of starch granules revealed by atomic force microscopy*, Studia Universitas Babes-Bolyai, Chemia, XLV, 2, Tom II, p. 119-126.