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Thermoplastic Extrusion- a Method to Produce Starch-Based Loose Fill Packaging

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Abstract: Bioplastic materials, where starch-based loose fill packaging can also be included, play an important role in the evolution of modern science and civilisation. As they have unbeatable benefits as compared to classical synthetic plastic materials, they are more and more used. This paper presents some aspects of producing loose fill packaging 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 in its five steps: order-disorder changes, nucleation, extrudate swelling, development of voids and void breaking.

Keywords: thermoplastic extrusion, loose fill packaging, starch.

INTRODUCTION

During the last years, the world has witnesses the concern for diminishing the plastic material waste, one of the main means of pollution of water and soil.

Synthetic plastic materials con tribute to environment pollution both during their production and their use, as well. Thus, chlorofluorocarbon (CFC), a clearing agent used to manufacture synthetic expanded plastics from petrochemical products, is a substance that damages environment a lot and affects the ozone layer. On the other hand, the long decomposition time (sometimes of tens or hundreds of years) leads to the accumulation of enormous amounts of waste originating in such products.

One of the solutions aiming at the reduction of the consumption of synthetic plastics lies in producing packaging with biodegradable, cheap, materials, originating in agriculture so that so-called “bioplastic” packaging that does not pollutes the environment can be made.

Bioplastics began to be recognised as a positive and significant invention of the chemical and plastics industry as they offer numerous and varied opportunities. The new class of bioplastics and biodegradable plastics presents a real concern for almost of sectors of society and industry.

The bioplastic materials research and development is still going on and aims at achieving a renewed economic cycle. It should be noticed that in a recent study performed in 2005, by the company BCC Research, packaging represented about 50% of the application of the bioplastics, and 2/3 of the packaging were represented by loose fill packaging.

The research performed until now have led to the conclusion that, in general, bioplastics and loose fill packaging especially, can be produced from vegetal raw materials, among which starch hold the first place.

In Fig. 1, there is a symbolic representation of the older situation when polysterene loose fill packaging was used and the present situation, when starch-based materials are used for packaging purposes and then can be used as fertilisers for the plant of origin of the raw material (www.starchtech.com).

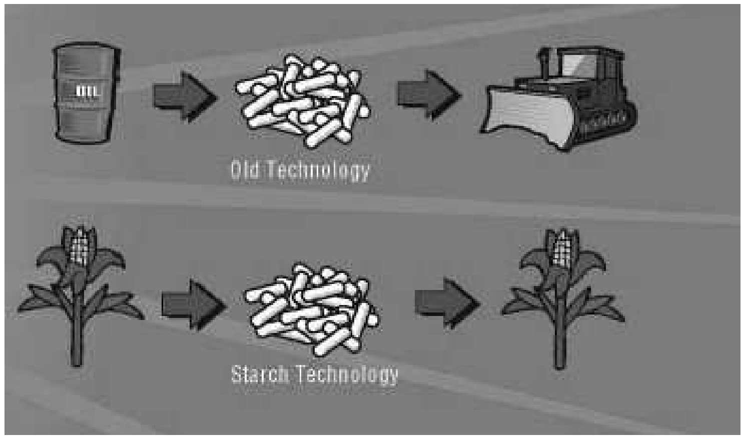

Fig. 1 Comparison of loose fill materials recycling

Starch is not only abundant, but very efficient from the point of view of its very good cost-performance rate. It can be found in many plants in the form of microscopic grains. While the most important starch sources in Europe, America and South Africa are corn, maize and potato, in Asia, tapioca is on the first place. With modern culture methods, a hectare of land can produce a crop that gives the raw material for two tons of bioplastic material.

The industrial processes of producing starch separate secondary products, such as proteins, oils and vegetal fibres, so that only very pure starch is left.

It was found that starch rich flowers are also useful to produce bioplastics.

Chemically, starch belongs to carbohydrates. It is formed of two component elements: amilopectine, having a branch structure, the main component, distributed in the grain around the second component, amylose, which has a linear structure.

Annually, over 45 million tons of starch are produced, and almost 10 million tons of it is made in Europe. Germany produces about 2 million tons of starch.

In Romania, starch processing capacities of over 20 000 tons/year exist and the raw material used is corn and maize.

PRODUCTION OF STARCH-BASED LOOSE FILL PACKAGING MATERIALS

Thermoplastic starch was invented in 1988, and, at present, is a leading material among bioplastics, with a market weight of over 80 %. Thermoplastic starch is, then, a relatively new concept, and one of the research targets in the manufacturing of biodegradable materials.

Starch is not an actual thermoplastic compound, but in the presence of a plastifier (water, glycerine, sorbitol etc.), of high temperatures (90°-180°C) and subjected to mixing-shearing processes it melts and becomes fluid, providing possibility of use with extrusion, injection, blowing equipment, similar to those used for synthetic plastic materials.

Research has shown that packaging and packaging elements based on starch can be achieved by thermoplastic extrusion, Fig. 2 indicating the place of the extruder in this circuit (www.starchtech.com).

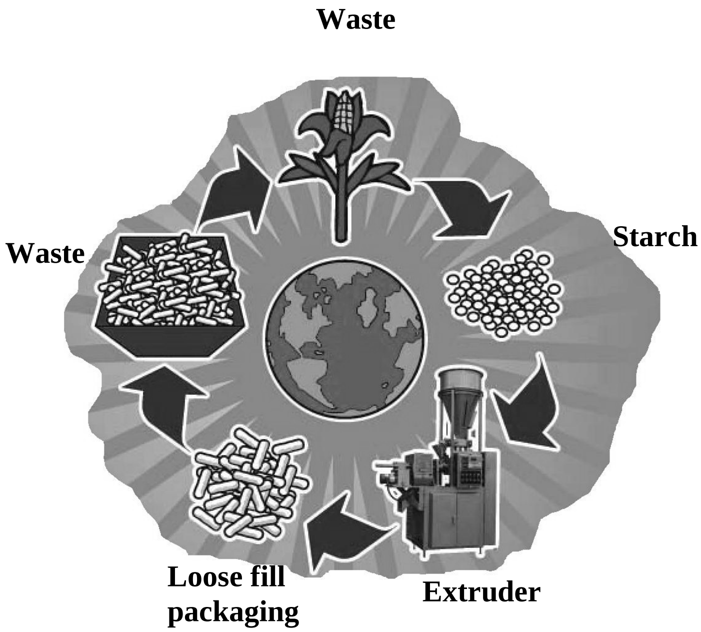

Fig. 2 Place of the extruder in the circuit of the starch-based package [8]

A representation of the extruder working diagram for the thermoplastic extrusion of loose fill packaging is presented in Fig. 3.

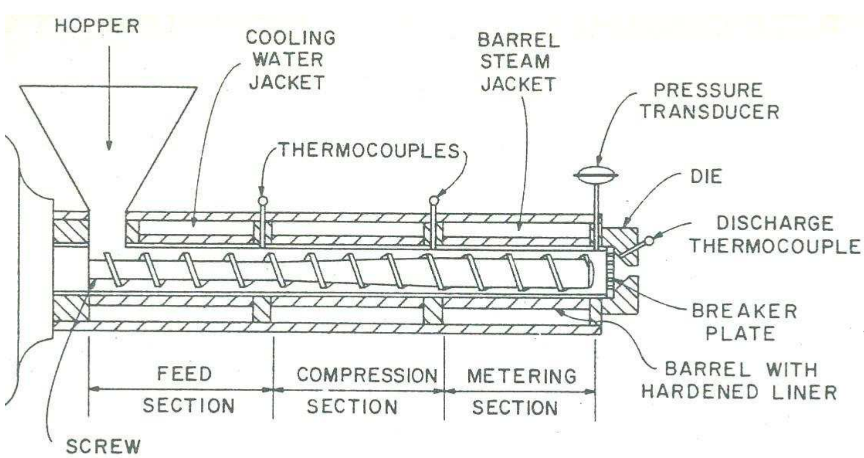

Fig. 3 Extruder diagram

The raw material, starch or flower, in the form of grains or powder, mixed with other ingredients according to the formula, is introduced in the extruder barrel through a hopper. In the barrel, one or two helical conveyors turn around engaging the grains and moiving them along the barrel. Internal friction due to the mechanical action of the helical conveyor and the heating sources placed around the barrel heat the grains and melt them, so that the material becomes homogeneously melted. The rotation of the helical conveyor contributes to the increase of pressure inside the conveyor and the melted material is forced through the die holes. The moisture of the melt and the sudden decrease of pressure when leaving the die make the product expand. Then it is cut to length and becomes loose fill biodegradable package.

The extruder presents three distinct areas along its length:

- the feed section, transporting the material from the feeding barrel to the conveyor central area,
- the compression (melting) section, where the heat generated by the polymer friction and heating sources bring about its melting, and
- the metering (pumping) section where mixing and melting continue with pressure increase.

PHENOMENA OCCURRING DURING STARCH THERMOPLASTIC EXTRUSION

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.

Fig. 4 shows the working diagram for the extrusion process with direct expansion of a partially crystalline polymer (Strahm, 1988). 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 Tg transition temperature and melting temperature Tm. As seen in the same diagram, Tg and Tm are influenced by the composition moisture content (Liu, 1999).

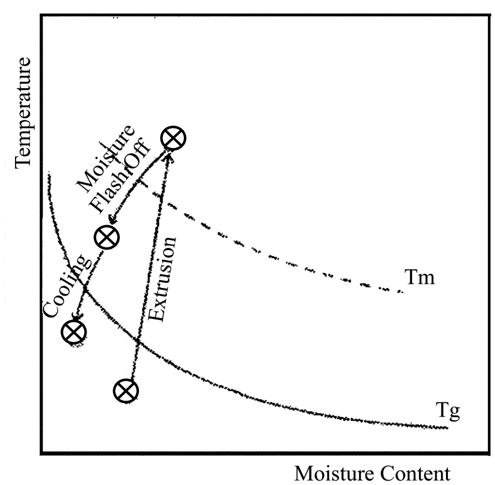

Fig. 4. Working diagram during extrusion with direct expansion

Analysing the operation of the extruder for direct extrusion according to diagram in Fig.4, 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 returns to its highly elastic state and then to the amorphous state. In fact, when the extrudate temperature decreases under Tv, 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 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.

Kokini et al. (2003) approach the various stages in the extrudate expansion and illustrate the expansion mechanism in the diagram shown in Fig. 5.

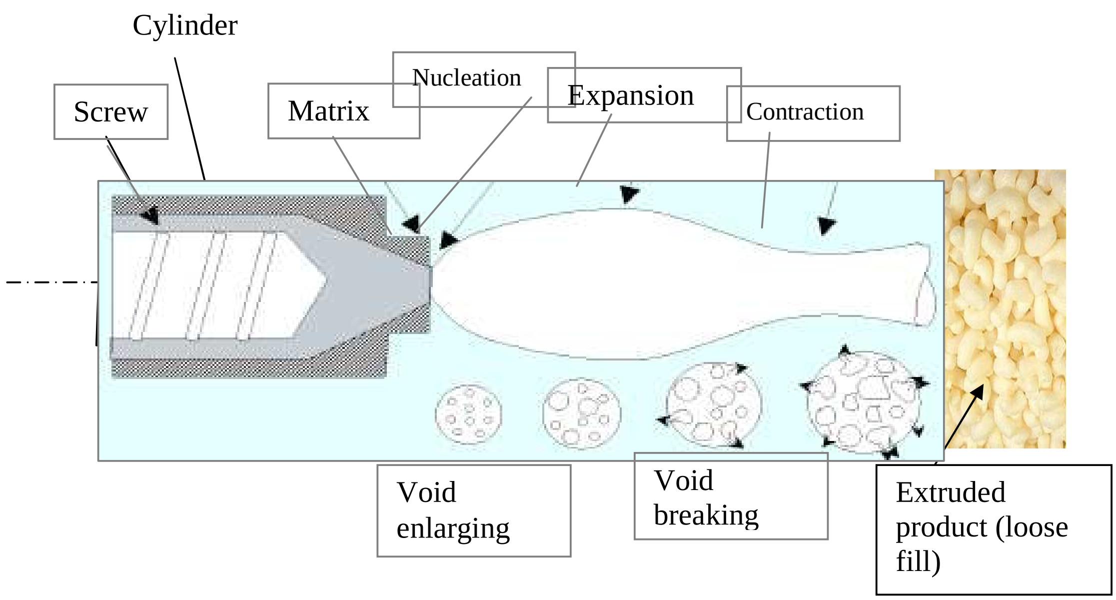

Fig. 5. Diagram of the expansion of the extrudate

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

CONCLUSIONS

Thermosetting extrusion provides for the required changes in producing starch/based loose fill packaging.

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 (formed) in the starch melt. In spite of the significance of this stage in the expansion of the extrudate, few studies on the nucleation phenomenon occurring during the extrusion of bipolymers exist. A sure reason lies in the complexity of the system and ongoing changes within the material during extrusion.

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.

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